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HYDRAULIC CHARACTERISTICS OF ACTIVATED SLUDGE SECONDARY CLARIFIERS

by

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16. ABSTRACT

This study documented the hydraulic characteristics of typical activated sludge clarifiers. Modifications to the clarifier structures were made in an attempt to improve clarifier hydraulic characteristics and performance. Innovative fluorometric dye tracer studies were used to observe the hydraulic flow patterns within several different types of clarifiers. Factors that are internal and external to the clarifier were found to affect the hydraulic characteristics and performance of the clarifiers investigated.

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

In this study the hydraulic characteristics of typical activated sludge clarifiers were documented. Modifications to the clarifier structures were made in an attempt to improve clarifier hydraulic characteristics and performance. Innovative fluorometric dye tracer studies were used to observe the hydraulic flow patterns within several different types of clarifiers. Factors that are internal and external to the clarifier were found to affect the hydraulic characteristics and performance of the clarifiers investigated.

Francis T. Mayo, Director

Municipal Environmental Research
Laboratory

ABSTRACT

This report presents the results of a series of hydraulic tests on eight activated sludge secondary clarifiers. These results and other observations at the plants have been interpreted to identify many of the factors believed to affect clarifier solids removal performance.

In most of the units, throughflow routes were found to be similar, but unlike the flow regimes described by clarifier hydraulic theory and suggested by commonly accepted design standards. Two exceptions were noted: Horizontal plug-flow was approximated in a large rectangular secondary and nearly uniform upflow was seen in a peripheral feed, peripheral overflow secondary under certain flow and blanket conditions.

An inlet-induced sludge jet was clearly defined in one center feed circular clarifier and there is evidence that persistent jets were features of several other center feed units. Effluent total suspended solids were reduced by 38% in one secondary by means of a peripheral baffle. It is believed that this baffle effectively reduced the jet effect.

A smaller center feed circular secondary with oxygen activated sludge exhibited a strong density flow and may have been adversely affected by excessive sludge header rotational speed. Header speed reduction by 56% decreased effluent solids by 10%. A mid-radius baffle/flocculation chamber which was intended to interfere with the density flow resulted in a further reduction of 37% in effluent solids.

A small rectangular secondary exhibited a density flow which scoured the sludge trough at the inlet end. Inlet distribution was poor. The clarifier was also adversely affected by a highly variable plant throughflow resulting from upstream liftstation operation. A combination of new baffling, inlet distribution and storage resulted in an overall reduction of 31% in effluent suspended solids.

The report includes discussions of the potential effects of several hydraulic disturbances on secondary clarifier performance. An unverified mathematical model predicts that flow variability is a significant cause of the transport of solids in the vicinity of the blanket.

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LIST OF ABBREVIATIONS

A.S. -- Activated Sludge
BOD -- Biochemical Oxygen Demand
Clar. -- Clarifier
cm -- centimeter
cm/s -- centimeter per second
COD -- Chemical Oxygen Demand
d -- day
diam -- diameter
EFF -- Effluent
ft -- feet
ft/sec -- feet/second
g -- acceleration due to gravity -- 32.2 ft/sec^2
gal -- gallon(s)
gpd -- gallons per day
hr -- hours
kg -- kilogram
km/h -- kilometers per hour
l -- liters
m -- meters
m^3 -- cubic meters
m^3/d -- cubic meters per day
$m^3/dx10^3$ -- thousand cubic meters per day
$m^3/m^2 \cdot d$ -- cubic meters per square meter per day
m/s -- meters per second
mgd -- million gallons per day
MCRT -- Mean Cell Retention Time
ML -- Mixed Liquor
MLTSS -- Mixed Liquor Total Suspended Solids
ml -- milliliter
mm -- millimeter
mph -- miles per hour
mg/l -- milligrams per liter
min -- minutes
P.O.D. -- Point of Discharge
ppb -- parts per billion
R.A.S. -- Return Activated Sludge
RASTSS -- Return Activated Sludge Total Suspended Solids
sec -- seconds
sq ft -- square feet
SSV_5 -- Settled Sludge Volume at 5 min (ml/l)
SVI -- Sludge Volume Index
TSS -- Total Suspended Solids
W.A.S. -- Waste Activated Sludge
WTP -- Waste Treatment Plant

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SECTION 1

INTRODUCTION

Properly designed and operated clarifiers are essential to the overall performance of virtually every municipal wastewater treatment process. Present design guidance for clarifiers is stated mostly in general terms with a few empirically derived factors such as those which relate overflow to surface area and weir length. There tends to be some uncertainty in the design community regarding the appropriate dimensional parameters, including basin shape and inlet and outlet configurations. The uncertainty is well justified, since hydraulic factors internal and external to the basins as well as upstream process and hydraulic considerations are numerous, highly variable and thus, extremely complex.

The initial purpose of this study was to utilize a common oceanographic tracer technique to define the flow patterns in activated sludge secondary clarifiers, to construct simple baffling to interrupt "short circuits" and to evaluate the performance of the newly baffled units. Routine observations related to the flow pattern studies caused a gradual and necessary evolution of the study into a broader based effort to identify as many as possible of the factors which cause excessive suspended solids to be discharged. Whenever possible, documentation of the cause and effect of excessive solids discharges was sought in one or more of the eight full scale clarifiers studied. In those cases where cause and effect could not be documented, the investigators looked to theoretical analysis backed by insight and visual observations.

A significant amount of research has been completed in the past on clarifiers. Although modified versions of commonly conducted dispersion measurements were made on all but one clarifier in this study, much of the data presented is not easily related to previous research. Some of the graphic and theoretical presentations are believed to be novel. For these reasons, a complete review of the literature is not presented.

Perhaps because of the somewhat different course this research has taken, the work has asked more questions than it has answered. These questions have already stimulated further research aimed at determining how and why activated sludge solids are transported, settled, and/or discharged from secondary clarifiers. Hopefully, a clearer understanding will lead to better performing process units.

SECTION 2

CONCLUSIONS

This project was developed based on the assumption that a clarifier's ability to properly separate an activated sludge from a treated wastewater was controlled by the unit's hydraulic characteristics given that the sludge had good settling properties. It was also thought that these hydraulic characteristics were controlled mainly by the clarifier's inlet structures. The clarifier's inlet structures were thought to be the major variable that could be altered to improve clarifier performance. At the conclusion of this project, it is apparent that many factors affect clarifier hydraulic characteristics and performance. Some of these factors are obvious and easily considered in facility design, while other are more subtle. The conclusions in no way refute the theories thought to control ideal clarifier behavior. However, few operating clarifiers were found to imitate the theoretical model.

An approach for evaluating and upgrading the hydraulic characteristics and performance of activated sludge secondary clarifiers was demonstrated. The key to this approach is to define the hydraulic characteristics and the distribution of solids within operating clarifiers. Traditional analytical tools such as dye dispersion tests are of little value in these situations because they only indicate that a problem exists, but not its cause. The procedures used in the project, mainly the Flow Pattern/Solids Distribution, Weir-Wall Solids, and Sludge Distribution Tests, when used by an experienced analyst, will result in a better understanding of the fluid behavior and solids distribution within the clarifier. This understanding can lead to methods for practical cost-effective upgrading of activated sludge secondary clarifiers.

Those clarifiers modified based on these evaluation procedures as part of the project experienced significantly improved performance after the implementation of the relatively modest modifications. These procedures are straightforward in application, but require some experience to interpret the data such that a successful clarifier modification will result. It is the opinion of the author that the procedure demonstrated in the project would be applicable to 80% of the existing activated sludge secondary clarifiers.

This project demonstrated that clarifiers that appeared adequate hydraulically based on present design guidance did not always meet performance expectations. The modifications implemented were shown to increase the real hydraulic capacity of the clarifiers by producing an effluent lower in suspended solids at equal flow rates. This conclusion can be extrapolated to infer that smaller and less costly clarifiers with equivalent performance are technically achievable.

There are numerous factors controlling clarifier performance. Some of these factors are related to the details of clarifier design. The other factors are related to the operation of the treatment plant.

The facility design engineer and appropriate review officials should be aware that designs that create nearly ideal flow can be achieved, but these clarifiers are not representative of the majority of units presently operating in the United States. The published design standards that many engineers must satisfy for federal and state approval of municipal plant designs are nonspecific, inadequate with regard to rationally developed design parameters, including surface area overflow rate, and, in the case of weir loading, such standards may actually be detrimental to clarifier performance. Flux theory, an alternative design procedure, does not recognize the reality of uneven solids distribution or operational problems that can occur with a sludge blanket too near the bottom of an inlet baffle.

Results of this project indicate that the design engineer must recognize some of the detailed features of the entire facility and clarifiers which can affect effluent quality. Specifically:

- The means for controlling hydraulic balance between clarifiers is often inadequate.

- Balance between inlet ports on an individual clarifier is sometimes poor.

- Operators seldom have adequate flow measurement devices to detect hydraulic imbalance.

- Upstream control valves can affect the performance of at least one type of peripheral feed, peripheral overflow clarifier.

- Density current jets are real, longitudinally persistent and detrimental to effluent quality. Inlet baffling fails to intercept these jets in some designs.

- Hydraulic sludge headers do not perform ideally; sludge distribution and removal is not uniform; some riser pipes tend to clog.

- Rotating sludge headers may operate at an unnecessarily high speed. Tip speed, per se, is not a rational design parameter.

- Small amplitude waves propagate rapidly through a gravity-flow plant, causing flow variations which degrade clarifier performance. Related disturbances from pump or wind induced seiche can also degrade clarifier effluent quality.

- The amplitude and frequency of flow variations, from whatever cause, are both related to higher clarifier effluent suspended solids.

Regardless of the details of clarifier structure, the initial pathway of the throughflow was remarkably similar in all clarifiers studied. Flow away from the inlet region of the units occupied a relatively thin layer just above the blanket. In all center feed and in the smaller rectangular unit studied, flow turned sharply upward at the weir wall proceeding to the surface. In the peripheral feed clarifier studied, a similar flow region existed above the blanket, but upturn was more gradual. In the study's large rectangular unit, slight vertical mixing near the inlet resulted in flow behavior and solids distribution which approached the theoretical ideal. Based on these observations, the investigator questions the widely accepted concept of inlet downflow on which the design of every clarifier included in this study was based.

The other factors found to affect clarifier hydraulics and performance, though non-structural in nature, must be recognized and considered by the facility designers and operators. One of the potentially controversial interpretations of these data by the author is that the settling properties of the activated sludge affect clarifier hydraulic characteristics. Results of this project indicate that sludges which settle rapidly tend to produce higher velocity density currents, high turbulence and higher effluent turbidity than slower settling sludges. Throughflow occurs within a range of solids concentrations, not on top of an ill-defined blanket. The selection of a blanket depth should not be based solely on storage or thickening concepts, but should take into account the blanket position with respect to the lower extremity of inlet baffles. With sludges which settle very slowly, the operator may be able to control a very high blanket to his advantage.

The second non-structural alternative which the operator can consider is based on the intuitive and theoretical proposition that unsteady flows degrade clarifier performance. Operators should try to identify any possible method to smooth plant flows. Methods might include the use of channels and gravity mains for storage, the use of smaller lift station pumps with longer duty cycles in lieu of large pumps with short duty cycles and the use of constant, low flow rate sludge recycle pumps instead of larger pumps operated with timers.

The reader will find that the conclusions just presented are based on an accumulation of data from the eight clarifiers included in this study and other clarifier studies and observations by the principal investigator and others cited. Very little rigorous proof can be produced by hydraulic studies, especially in wastewater. However, the sum of the data which will be presented cannot be ignored.

SECTION 3

RECOMMENDATIONS

The major recommendation of this report is that those responsible for facility design, establishment of design criteria, and review of plans and specifications acknowledge the complex nature of clarifier hydraulics and how they affect overall facility performance. There is a common perception that clarifiers are basically simple process units with only a few variables controlling their design and performance. When a clarifier is not performing properly, it is usually thought to be undersized; simply just not big enough. A major goal of this report is to dispel any myth about clarifier simplicity since many complex phenomena have been found to control performance that are entirely unrelated to size.

In most of the designs investigated to date, inlet structures do not control the flow regime or solids transporting phenomena in the tanks. The initial settling characteristics of the mixed liquor and the level of blanket with respect to inlet baffles need to be carefully considered by plant operators and/or clarifier analysts.

There is a strong indication that the common inlet downflow concept is not optimum. Good vertical distribution near the inlet, as suggested by most published design standards, may be superior. This radical revision of inlet designs merits serious investigation by trial in retrofitted full-scale clarifiers.

Facility designers and operators should acknowledge the potentially adverse impacts of peak flows on clarifier performance. Designers should make certain that any pump station design assures that large pump induced peak flows are not imposed on the facility. Operators must be aware that other operations in the facility such as return of sidestreams and intermittent underflow practices can severly influence the peak flows and loads received by the treatment processes unless properly considered in the facility design. Transient flows are thought to have a significant impact on activated sludge secondaries in particular. More research is needed to fully define the effects of amplitude and frequency of transients on solids transport. However, such investigation should follow the development of better inlet designs.

Adequate hydraulic control is essential to proper operation of activated sludge secondary clarifiers. The operator must be able to accurately measure and control the flow to parallel clarifiers at varying flow rates. Imbalances between parallel units may be neither obvious to the operator without proper measurement nor controllable if measured. Sophisticated instrumentation and automation is not required. Simple methods of flow distribution and measurement are available, but dynamic effects must be recognized.

There are relatively inexpensive techniques that can be used to extend the hydraulic capacity and/or improve the performance of existing clarifiers. At facilities that are experiencing clarifier related performance problems, additional clarifiers should not be constructed without thoroughly investigating the performance potential of the existing tanks using evaluation techniques such as those described in the report.

SECTION 4

METHODS AND PROCEDURES

GENERAL

This project was intended to provide a better understanding of the factors controlling the performance of activated sludge secondary clarifiers. Secondary clarifiers are required in activated sludge process to separate the biological solids from the treated wastewater while retaining the solids in the system. The performance of these clarifiers is measured by their ability to pass the treated liquid through the system while providing suitable conditions within the clarifier for separation and retention of the solids.

It was necessary to use procedures in the project that could measure the movement of both the liquids and the solids within fullscale operating clarifiers. Generally, dye tracer techniques were used that either attached ("tagged") themselves to only the liquid or the solid within the clarifier.

Most of these procedures have never been widely applied to the analysis of activated sludge secondary clarifiers or described in the literature. For this reason they are presented here in some detail.

MULTI-POINT DISPERSION TEST

This test is a variation on the dye dispersion tests which have been performed on clarifiers in the past to quantify the amount of hydraulic "short circuiting" occurring in the basin. These dye dispersion tests measure the time required for the movement of a "slug" of dye tagged to the liquid as it passes through the clarifier. The procedure consists of the instantaneous injection of a specific quantity of dye at the inlet to the clarifier and the measurement of its concentration in the effluent with time.

It is believed by some that standard dye dispersion tests will show whether or not a clarifier has hydraulic problems that may be affecting its performance. They do not provide any insight as to the causes of the problems. The multi-point dispersion test was developed to improve this test so that it would provide some indication as to the causes of hydraulic problems.

Instead of measuring the dye concentration with time at one point representing the entire effluent of the clarifier, this test divides the clarifier into several segments with the measurement of the dye concentration in the effluent with time from each segment. These results are intended to show if the clarifier behaves differently in different segments.

A multi-point dispersion test begins with the bulk release of Rhodamine WT fluorescent dye at a convenient point with good mixing between the aeration basin and the clarifier being evaluated. Approximately 50 ml of Rhodamine WT dye should be added per 1.0 mgd (3800 m^3/d). The dye should be added as quickly as possible so as to create a "slug" of material passing through the clarifier.

Following the release, samples of clarifier effluent are taken at from 3-6 previously marked and widely separated locations at the overflow weirs. Samples are taken at 5 min intervals for at least 1 hr, or until the clarifier surface appears uniformly colored. After this time, the sampling interval is gradually increased to as much as 1 hr, since the "tail" of the dispersion curve invariably shows a smooth decline in tracer concentrations. After fluorometric analysis for dye concentration, the individual weir stations' dispersion curves are corrected for background fluorescence value, placed in non-dimensional format and plotted as in Figure 1.

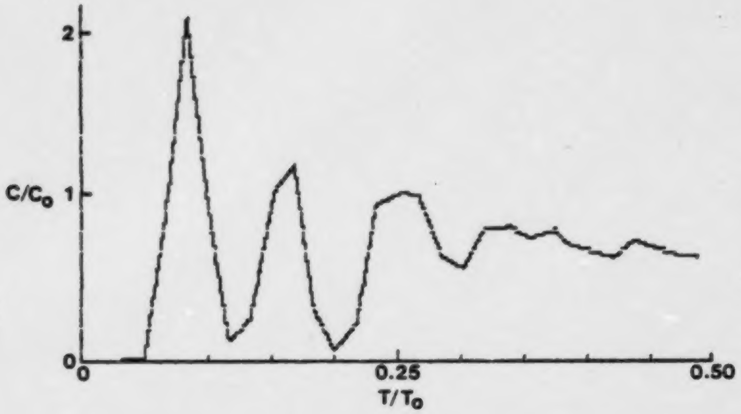


Figure 1. Example of a Multi-Point Dispersion Curve for one sampling point.

It is the opinion of the author, that both standard dye dispersion tests and multi-point dispersion tests are of little value in the analysis of the hydraulic characteristics of activated sludge secondary clarifiers. Though they may indicate the presence of hydraulic problems, they cannot show their causes. These tests were performed at a number of the clarifiers included in this study. The results are included in this report though they are considered to add little to the understanding of the hydraulic phenomenon within the clarifier.

FLOW PATTERN/SOLIDS DISTRIBUTION TEST

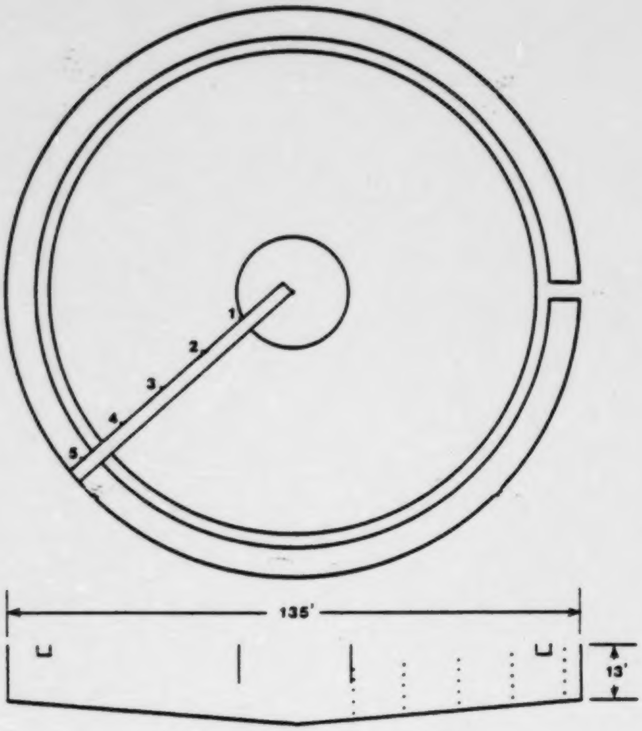
Dye dispersion tests are useful in identifying clarifiers whose performance may be limited by their poor hydraulic characteristics. They are of little value in defining the causes of the poor performance or how they can be corrected. The results from flow pattern/solids distribution tests were used in this project because they can be used to infer the hydraulic characteristics within a full-scale operating clarifier from which rational modifications can be developed that will result in improved performance.

In this test, a continuous injected stream of Rhodamine WT "tags" the liquid portion of the mixed liquor as it flows from the aeration basin to the secondary clarifier. The hydraulic characteristics are inferred from the measurement of the progression of the "tagged" liquid as it displaces the contents of the clarifier. This progression is determined from a series of flow patterns that show the dye concentrations within a radial or longitudinal section of the clarifier at a specific time.

The first step in this test is to define a representative section of the clarifier where the measurements will be made. Selection of a cross section will depend on the configuration of the clarifier. A series of sampling points are then established to define the section, as shown in Figure 2, consisting of five or more points radially or longitudinally and five or more depths at each of these points.

A continuous stream of Rhodamine WT dye is then added upstream of the clarifier. Complete mixing of the dye with the liquid is essential before it enters the clarifier. Approximately 0.5 ml/min of dye per mgd (3800 m^3/d) of flow to the clarifier will produce an acceptable flow pattern.

After the dye has been entering the clarifier for approximately 15 minutes, the first flow pattern is measured. The flow pattern is based on the dye concentration at the sampling points defined earlier in the clarifier's cross section at the time of sampling. Theoretically, all of the samples would be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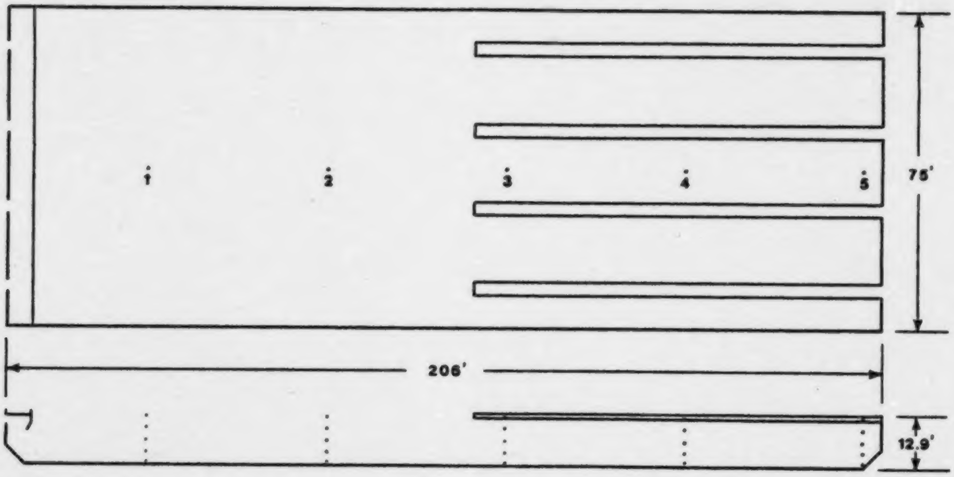
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Rectangular Clarifier

Figure 2. Plan and elevation of typical circular and rectangular clarifiers showing location at sampling points for Flow Pattern/Solids Distribution Test.

taken simultaneously. In reality, it takes a short period of time to collect the 25 or more samples required for a flow pattern. Initially 3-5 minutes were required to collect these samples, with a pump and hose. With further refinement in technique and apparatus, as many as 50 discrete samplers were used to collect a sample set for a flow pattern within 30 seconds.

The samples are collected in 300 ml BOD bottles where the solids are permitted to settle leaving a dye "tagged" supernatant. After settling, 8-9 ml of the supernatant is decanted with disposable borosilicate glass cuvettes. The dye concentration in each cuvette is then measured fluorometrically.

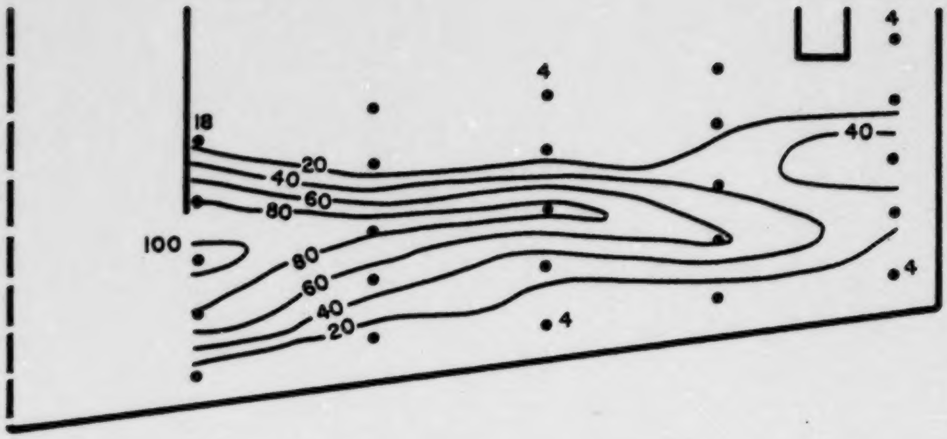
Following the determination of the dye concentration of the samples, the flow patterns are created by plotting the data on scaled sectional drawings of the clarifier. An example is shown in Figure 3. The contour lines represent lines of equal dye concentration. The flow pattern drawings which result are then examined to estimate the pathway of the dye throughout the cross section. The dots are the sampling points.

When the dye concentrations are plotted on the sectional drawings, some changes are made for clarity of presentation. The dye concentration flow patterns have the vertical scale exaggerated so that the differences between the dye concentration profiles are better defined.

The second part of this test measures the distribution of the total suspended solids (TSS) within the clarifier. It is the purpose of this part of the test to determine the distribution of the TSS which has resulted from the hydraulic characteristics defined by the flow patterns.

A solids distribution is based upon the TSS of the remaining liquid in the sample bottle after the supernatant for the dye measurements has been removed. This data is plotted in the same manner as the flow pattern, but with contours of equal TSS concentrations. Figure 4 shows an example of a solids distribution profile. For the solids distribution profile, the square root of the TSS is plotted and contoured. This technique aids in the visualization of the high solids concentrations near the bottom of the tank as well as the lower solids concentrations in the upper portion of the water column.

The number of flow patterns and solids distribution profile needed to infer the hydraulic characteristics within a clarifier will depend on the experience of the analyst. At the beginning of this project, a series of three flow patterns was generated before the dye had dispersed to all regions of the clarifier. Later in the project, it was found that a single flow pattern and solids distribution profile could be used to successfully infer the clarifier's hydraulic characteristics.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4
4

Figure 3. Example of a flow pattern showing lines of equal dye concentration in a radial section of a center feed circular clarifier. Note that the vertical scale is exaggerated as described in the text.

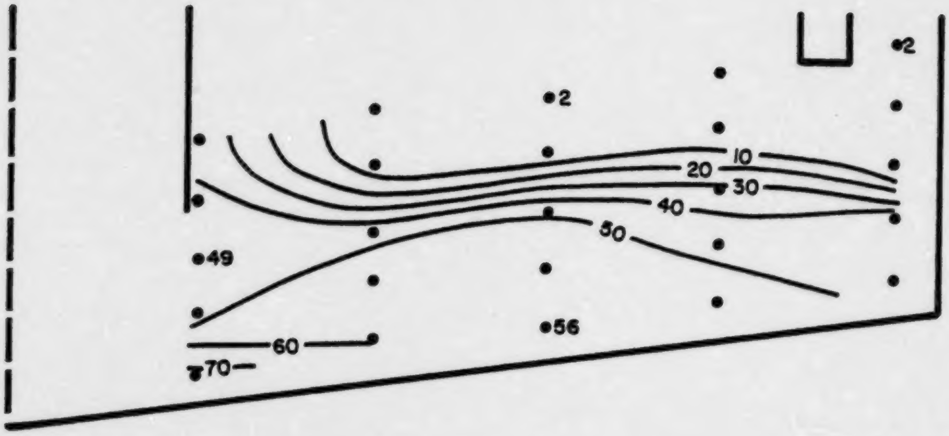

2
2
10
20
30
40
50
49
60
70
56

Figure 4. Example of a solids distribution profile showing lines of equal TSS concentration in a radial section of a center feed circular clarifier. Note that the square-root of the concentration is plotted for reasons described in the text.

Timing of the sampling in relationship to the movement of the sludge removal mechanism beneath the surface is critical so as to avoid entanglement of the sampling apparatus. Also, all materials used in the sampling procedure should be of white polyethylene, polypropylene or borosilicote glass in order to avoid uptake and re-release of the dye.

During the first several flow pattern tests, dye loss on the biological solids at each of the five sampling depths was measured by comparison with a volumetric distilled water dilution of the injected dye. The test required a great deal of field time and results were uncertain. The dye loss test was eventually abandoned because of the very small changes which sample data correction seemed to make on the final flow patterns.

WEIR-WALL SOLIDS TEST

This procedure was used to detect the influence of rotating sludge header mechanisms on the vertical solids distribution at the peripheral wall of circular clarifiers. Numerous observations by plant operators and by this investigator strongly suggested a correlation between the period of header rotation and the appearance of solids clouds near the weirs.

The test is simply a time-series of TSS concentrations at as many as 5 depths at a single location near the clarifiers peripheral wall. The sampling interval is 2 min for all depths and the total test duration is at least 1 revolution of the header mechanism, typically 36 min. The 19 or more samples retrieved from each depth are plotted against time as shown in Figure 5.

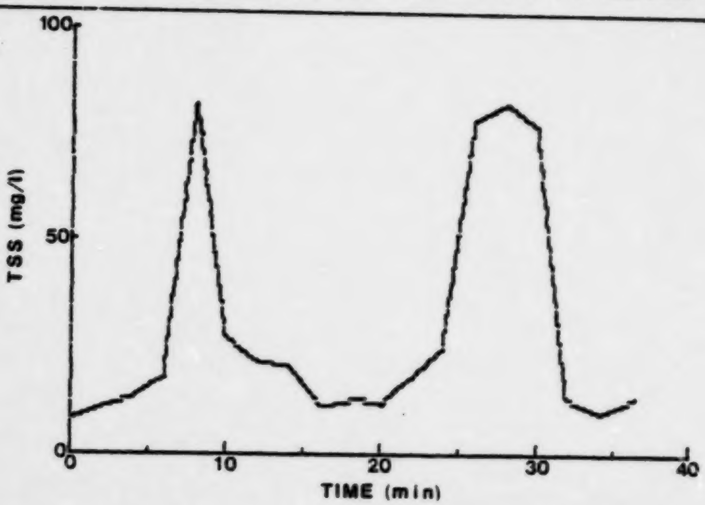


Figure 5. Example of results from a Weir-Wall Solids Test.

SLUDGE DISPERSION/SLUDGE JET TEST

The dye dispersion and flow pattern/solids distribution tests "tag" the liquid passing through the clarifier with a dye to measure its movement. In the sludge dispersion/sludge jet tests a portion of the activated sludge is "tagged" with a different type of dye to determine where the sludge is transported within the clarifier. This dye is called Oil Red "O" dye and is different in that it is insoluble in water, but readily absorbed by the activated sludge.

For each of these tests, a water emulsion of 3 kg of Oil Red "O" dye is thoroughly mixed with 10 gallons of activated sludge mixed liquor and released over a 1 minute period upstream of the clarifier. These tests differ in that they are used to define different aspects relative to the transport of sludge within the clarifier.

The sludge dispersion test measures the dye concentration in the return sludge with time. This gives an indication of how long the sludge is retained within the clarifier. Figure 6 presents typical results from this test.

The sludge jet test is a new procedure developed for this project to determine where the "tagged" sludge is transported within the clarifier. A section of the sludge blanket within a plane parallel to the periphery of the clarifier is defined at mid radius. Samples within the sludge blanket at the section are collected and analyzed with the results plotted similar to those for the flow pattern/solids distribution test. The reader is referred to the discussion in section 5 of the results from Stamford, CT where this test was used.

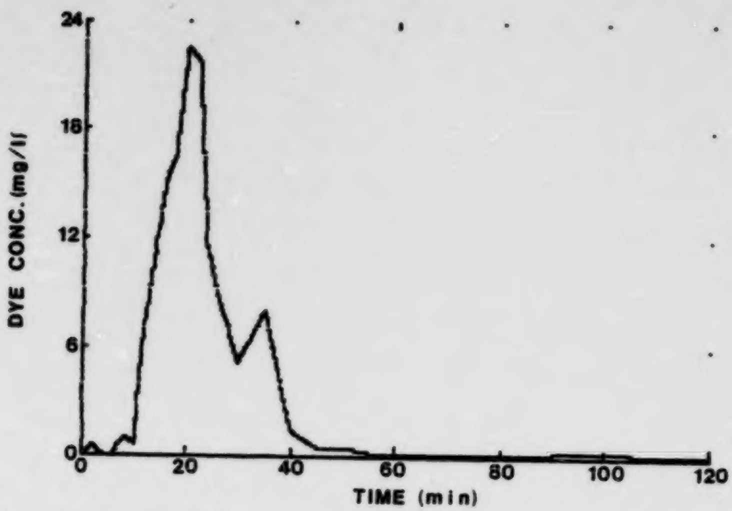


Figure 6. Combined Sludge Dispersion characteristic for Stamford secondary clarifier #2, 21 October 1980.

SECTION 5

RESULTS AND DISCUSSION

GENERAL

The initial goal of this study was to determine the flow patterns in several common activated sludge secondary clarifier configurations, to mechanically modify the patterns by baffling to decrease short circuiting, and to compare the effluent performance of a modified clarifier with another identical, but unmodified unit operating in parallel. To accomplish this, it was necessary to search widely for well operated municipal wastewater treatment plants with two or more parallel secondary clarifiers which were not performing as well as might be expected. The ideal combination of interested and cooperative operating staff, flow instrumentation, consistently good process control and numerous clarifiers downstream of a common aeration basin was not easy to find.

Ultimately, clarifiers in seven municipal wastewater treatment plants were included in the study. It is a gross oversimplification to state that only three types of secondary clarifiers were evaluated: rectangular; center feed, peripheral overflow; and peripheral feed, peripheral overflow. Actually, each of the configurations is unique.

This section of the report includes pertinent background information, the results of hydraulic studies, a description of five modifications made at three of the sites and performance evaluations on those modifications. Although the data are presented as eight independent studies, an inescapable result was that observations at each location led to changes in the study procedures at all successive locations. This learning process pre-dated this study by nearly two years[1]. Additional, privately funded clarifier investigations have provided more data. Another complication to a "clean" presentation of the available data is that the order of presentation is alphabetical, by site, not chronological. This order of presentation is a compromise made necessary by the fact that measurements and evaluations at many of the plants were concurrent, or overlapping. A chronological presentation, which would simplify understanding of the learning process by the reader would, it is believed, detract from the usefulness of the information by the reader who is interested only in one plant/clarifier configuration.

Each of the site discussions below includes a plan and elevation drawing of the clarifier evaluated. These are all drawn to the same scale so that their relative sizes can be compared. The drawings also show the sampling points for the Multi-Point Dispersion and Flow Pattern/Solids Distribution Tests. On the plan views, the capital letters on the periphery indicate the sampling points for the Multi-Point Dispersion Test, while the numbers indicate location of the sampling stations for the Flow Pattern/Solids Distribution tests. Sampling depths at these numbered stations are shown, to scale, as dots on the elevation view of these drawings. At the sites which included the Weir Wall Solids Test, the station location is identified in the appropriate results discussion. At Stamford, CT, two plan and elevation drawings are provided to identify stations for the separate studies of clarifiers #1 and #2.

The reader will find that the hydraulic study information provided for each site differs. Three reasons account for these differences:

1. Each plant had a different hydraulic configuration and presented an apparently unique problem to the investigator. Thus, each test series is site specific. Modifications and subsequent comparative tests were completed at only three plants included in this study, although five modifications were evaluated at the three plants.

2. The test procedures evolved gradually, and more or less emphasis was placed on certain tests as the study progressed. Several new tests were developed during the project.

3. Laboratory facilities and process test procedures were different at each facility. The investigator tried to utilize data normally collected for the operation of that plant in order to minimize disturbance to the facility's routine workload. Hydraulic tests were sometimes conducted on weekends, when laboratory support was not available. Thus, some test results do not include auxiliary process data.

Table 1 summarizes some relevant information on the facilities evaluated as part of this project.

TABLE 1. PROJECT FACILITIES SUMMARY

Location	Process Type	Plant Design Flow (m^3/d)	Clarifier Type*	Dimensions (m)	Side Water Depth (m)	Design Surface Overflow Rate ($m^3/m^2/d$)	Sludge Removal Mechanism	Tests Performed	Modification Implemented
Albuquerque, NM	Air-activated sludge	148,000	CFPO	41 (diam)	4.0	27.8	Riser pipes	1,2,3	N
Dallas County, TX--Ten Mile Creek Regional Waste Treatment Plant	Air-activated sludge	25,500	CFPO	32 (diam)	3.7	32.1	Riser pipes	2	N
Holly Hill, FL	Mechanically activated sludge	4,540	R	20 (L) 4.9 (W)	2.7	23.5	Chain and flight	1,2	Y
Morganton, NC	Pure-O_2-activated sludge	30,300	CFPO	24 (diam)	3.0	32.6	Riser pipes	1,2,3	Y
Oakland, CA--East Bay Municipal Utility District									
Main Plant	Pure-O_2-activated sludge	636,000	PFPO	43 (diam)	4.3	26.5	Suction header, single tube	1,2	N
Process Water	Pure-O_2-air-activated sludge	3,780	CFPO	14 (diam)	3.0	25.6	Riser pipe and rake	1	N
Orange County, FL--Sand Lake Waste Water Treatment Plant	Air-activated sludge	114,000	R	63 (L) 23 (W)	4.0	19.7	Traveling bridge with air lift	1,2	N
Stamford, CT	Mechanically activated sludge	75,700	CFPO	40 (diam)	4.0	30.6	Riser pipes	1,2,3,4	Y

*CFPO - center feed - peripheral overflow.
PFPO - peripheral feed, peripheral overflow.
R - rectangular.
Test #1 - Multi-Point Dispersion.
Test #2 - Flow Pattern/Solids Distribution.
Test #3 - Weir-Wall Solids.
Test #4 - Sludge Dispersion.
Y - yes.
N - no.

DATA COLLECTED AT THE SPECIFIC SITES

Albuquerque, New Mexico

Facility Description--

For this project, hydraulic measurements were completed at the City of Albuquerque's Plant No. 2 wastewater treatment facility. This facility uses an air activated sludge process treating raw wastewater from the community blended with the effluent from an adjacent trickling filter facility. A schematic of the facility is shown in Figure 7.

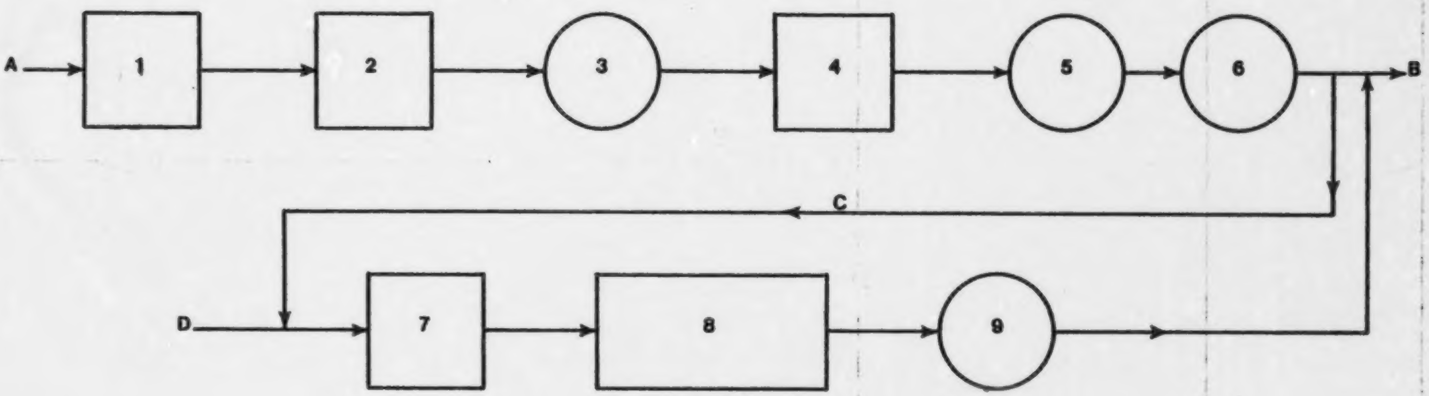
The plant uses four, 135 ft (41.1 m) diameter center feed peripheral overflow (CFPO) secondary clarifiers, shown schematically in Figure 8. The sidewater depth is 13 ft (4.0 m). A bottom slope of 1:12 provides a maximum depth at the center of the clarifiers of 18.4 ft (5.6 m). Design effluent rate for each unit is 10 mgd (38,000 $m^3 \cdot d^{-1}$). The inlet feedwells have solid walls and are approximately 26 ft (7.9 m) in diameter with a submerged depth of 9 ft (2.7 m). Sludge is removed by 10 riser pipes distributed along the scraper arms. The clarifiers are fitted with weirs at the peripheral wall and additional weirs on either side of a cantilevered trough, at radii of 57 ft (17.4 m) and 60 ft (18.4 m). A scum baffle and skimmer are provided for the inner region of the surface. Skimmer and riser pipe rotation rate is 1 revolution per 35.9 min.

Propeller type flow meters are provided on the sludge return line from each clarifier, but there is no individual flow measurement on the overflow or influent to the clarifiers. Flow enters the four clarifiers from a common mixed liquor source through a gate valve.

Only the initial hydraulic tests were conducted at this site because severe hydraulic deficiencies could not be found. No modifications were attempted and only limited performance data are presented.

Hydraulic Test Results--

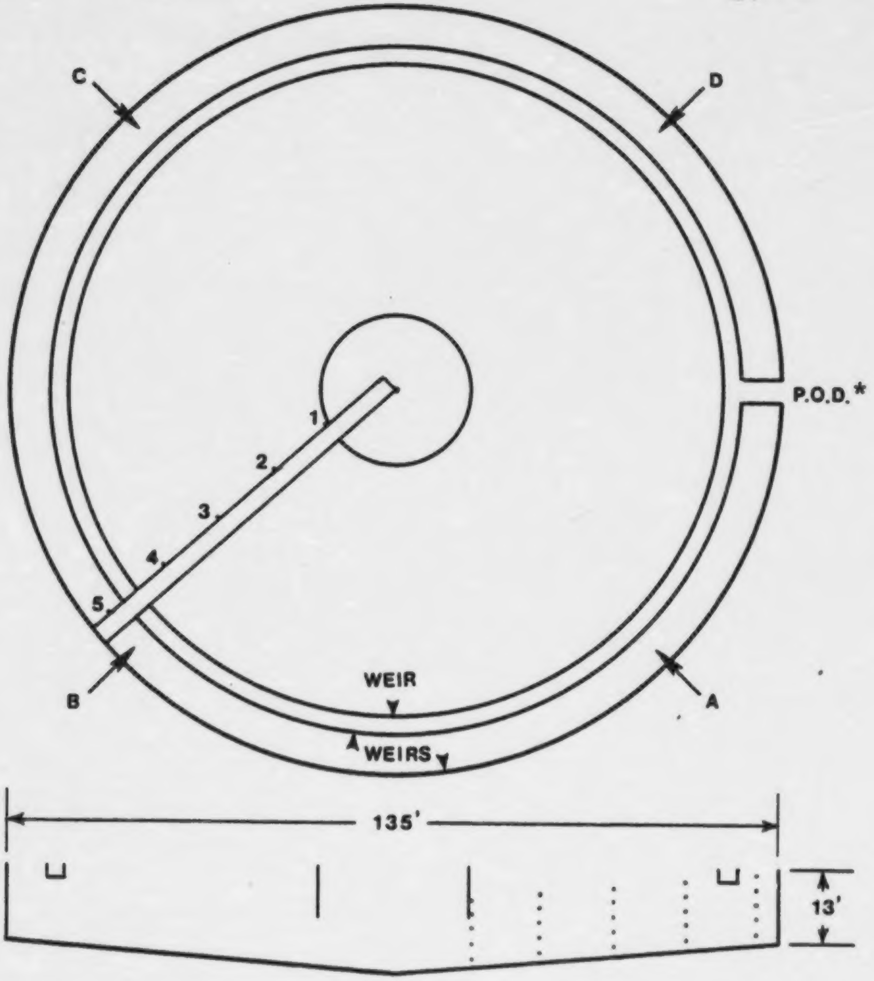
A Multi-Point Dispersion Test was performed at four stations between the concentric weirs of clarifier #1 on 20 June 1979. The data were put in non-dimensional format, then integrated to calculate relative dye mass in each direction and the median apparent detention time. The physical data pertinent to the dispersion plots is presented in Table 2. The dispersion plots are presented in Figures 9 through 12.



1. Bar Screens
2. Grit Chamber
3. Primary Clarifiers
4. Primary Pump Station
5. Trickling Filter
6. Trickling Filter Secondary Clarifiers
7. Activated Sludge Pump Station(Screw Pumps)
8. Aeration Basin
9. Activated Sludge Secondary Clarifiers

A. Influent - Trickling Filter
B. Effluent - Both Plants
C. Trickling Filter Effluent to Air Activated Sludge
D. Raw Wastewater to Air Activated Sludge

Figure 7. Process schematic for the Albuquerque Plant No. 2 wastewater treatment facility.


C
D
P.O.D.*
1
2
3
4
5
B
A
WEIR
WEIRS
135'
13'

*Point of Discharge

Figure 8. Plan and elevation of the Albuquerque Plant No. 2 activated sludge secondary clarifier #1.

TABLE 2. PHYSICAL DATA PERTINENT TO THE DISPERSION TEST ON ALBUQUERQUE SECONDARY CLARIFIER #1, 20 JUNE 1979

Background fluorescence = 1.6 ppb
Tank volume = 158,000 gal
Average effluent rate during test = 10.5 mgd
Average underflow rate during test = 5.42 mgd
Retention time based on influent rate, T_o = 143.2 min
750 ml of dye added to test clarifier only
Flash mix fluorescence, C_o = 125 ppb

Weir Station	Relative Dye Mass Overflowing Weir Station	Median Retention Time for This Test (min)
A	0.472	91.8
B	0.394	92.9
C	0.575	83.5
D	0.479	96.7

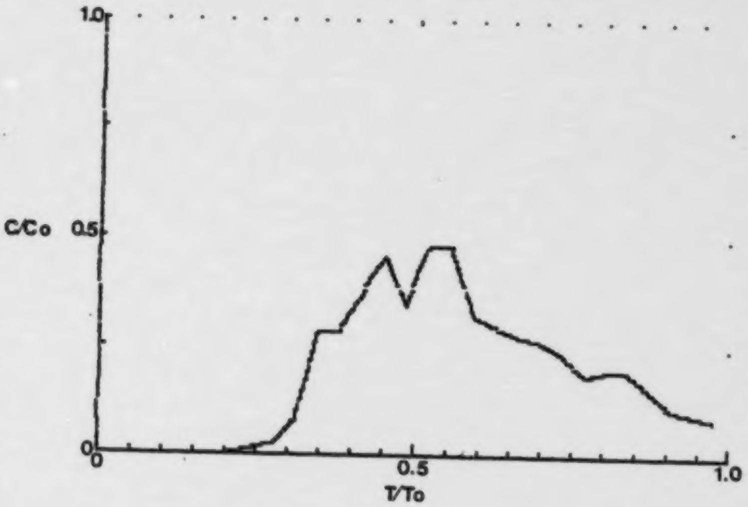


Figure 9. Results of the Multi-Point Dispersion Test for Albuquerque secondary clarifier #1, weir station A, 20 June 1979.

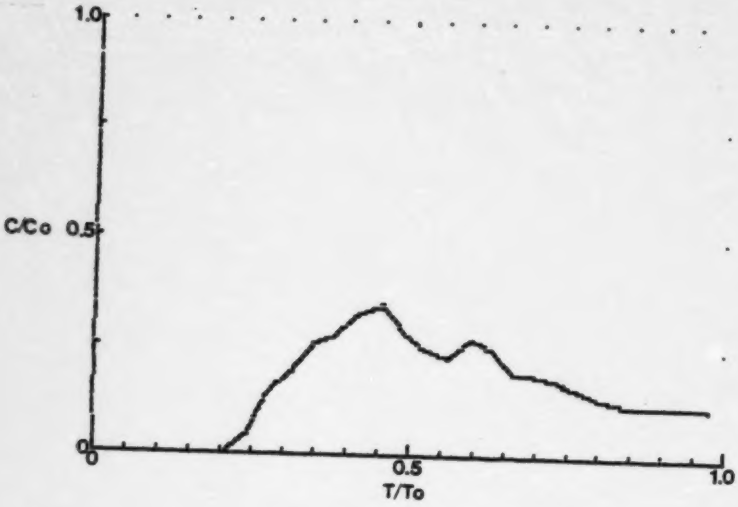


Figure 10. Results of the Multi-Point Dispersion Test for Albuquerque secondary clarifier #1, weir station B, 20 June 1979.

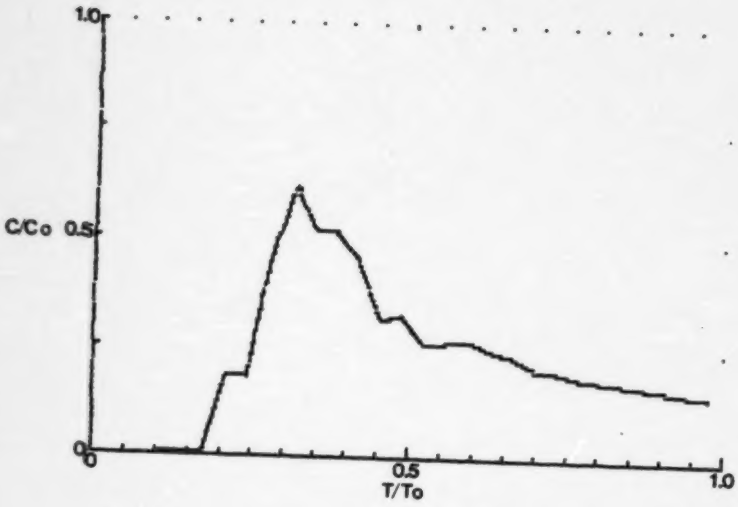


Figure 11. Results of the Multi-Point Dispersion Test for Albuquerque secondary clarifier #1, weir station C, 20 June 1979.

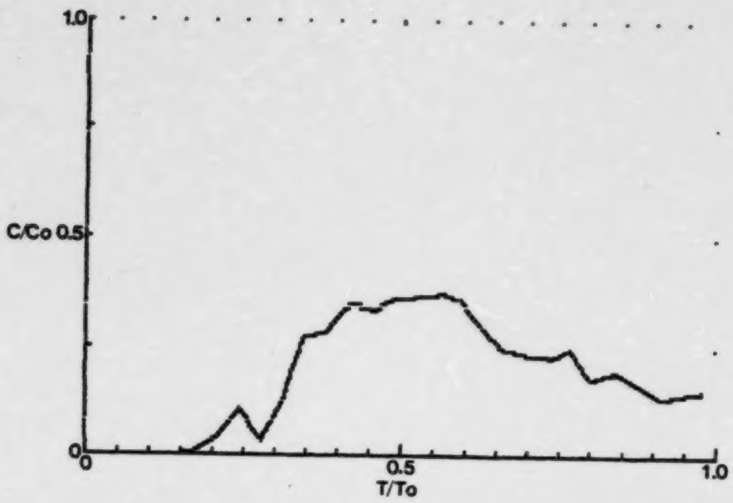


Figure 12. Results of the Multi-Point Dispersion Test for Albuquerque secondary clarifier #1, weir station D, 20 June 1979.

A Flow Pattern/Solids Distribution Test was conducted on 21 June 1979. During this test series, Rhodamine WT was continuously injected at a rate of 15 ml/min at the upstream end of the distribution channel, beginning at 1320. Three sample runs, which included 5 depths at each of five radial stations, were made along the access bridge. The first of these runs was started at 1337 and 5 minutes was required to retrieve all 25 samples.

Samples from all three flow pattern runs were fluorometrically analyzed for dye concentration. The third run's samples were also analyzed by the plant's lab for total suspended solids (TSS). Average effluent rate for the test clarifier was 9.91 mgd (37,510 $m^3 \cdot d^{-1}$). This corresponds to a surface area overflow rate of 693 gpd/sq ft (28.23 $m^3 \cdot m^{-2} \cdot d^{-1}$). Sludge blanket depth, measured by optical sensor at 1120 (middle of bridge) was 11.7 ft (3.56 m) below the surface. The return sludge rate was 5.47 mgd (20,700 $m^3 \cdot d^{-1}$).

Contours of dye concentration for the three runs are presented in Figures 13 through 15. The distribution of solids in the same radial section, analyzed from run #3 is shown in Figure 16.

In Figure 13, the 40 ppb contour at the outer wall hints of the flow rebounding, but this is not supported by Figures 14 and 15. Figure 14 shows a high dye concentration at one station near the surface outside the baffle ring which is unexplained

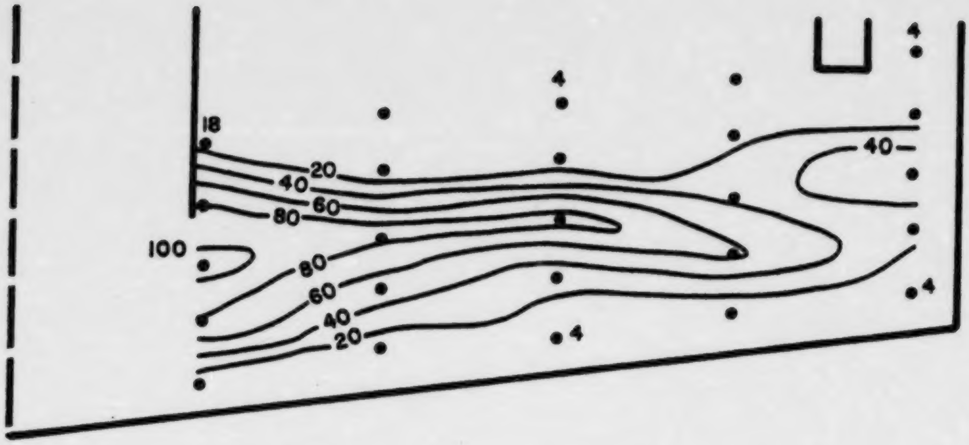


Figure 13. Radial distribution of the dye concentration in the Albuquerque secondary clarifier #1, 19 minutes after the start of continuous dye injection, 21 June 1979.

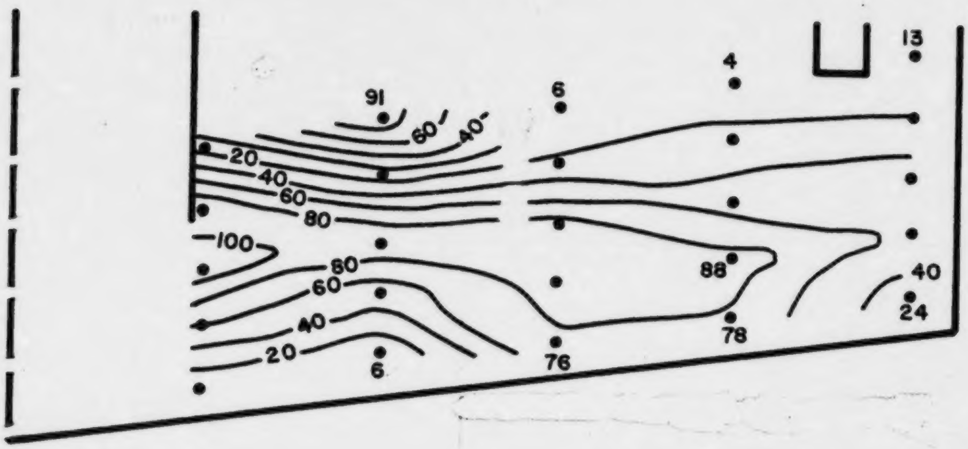


Figure 14. Radial distribution of the dye concentration in the Albuquerque secondary clarifier #1, 37 minutes after the start of continuous dye injection, 21 June 1979.

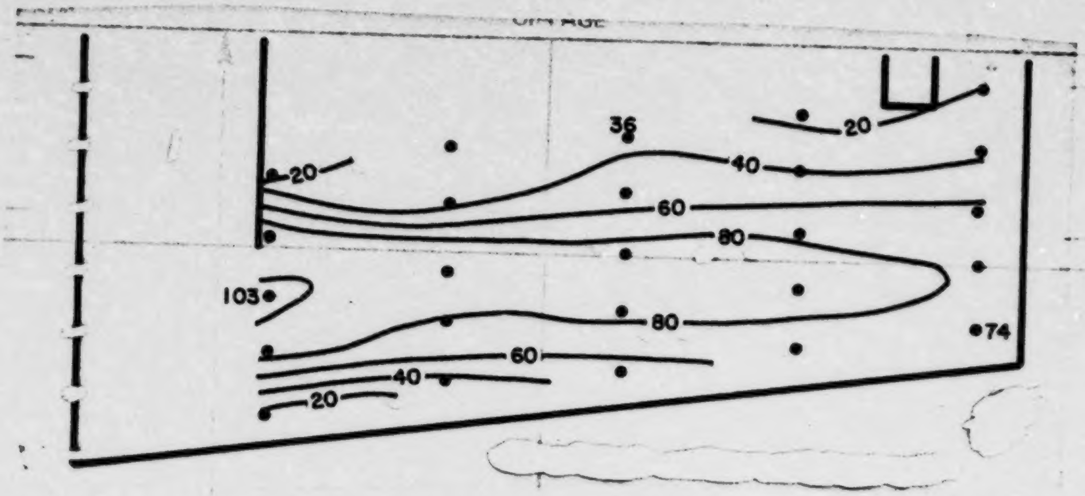


Figure 15. Radial distribution of the dye concentration in the Albuquerque secondary clarifier #1, 55 minutes after the start of continuous dye injection, 21 June 1979.

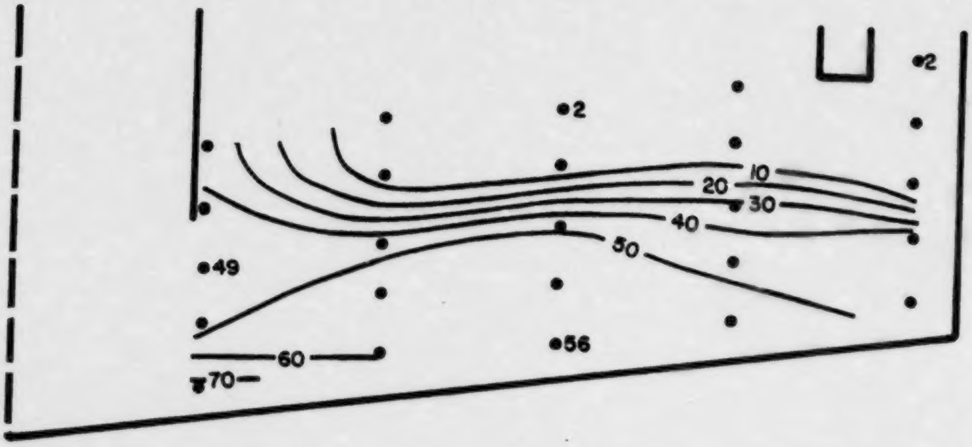


Figure 16. Radial distribution of the square root of total suspended solids in the Albuquerque secondary clarifier #1, 21 June 1979.

and not repeated. The shapes of the 60 and 80 ppb contours in the lower portion of Figure 14 indicate that one or two of the sludge riser pipes on one arm are drawing more than the other riser pipes. Figure 14 is a "snapshot" of the dye distribution just after passage of the arm which appears to be hydraulically unbalanced. Figures 13 and 15 are "snapshots" after passage of the other header arm on which riser pipe "draw" seems to be more balanced.

A Weir-Wall Solids Test was also conducted on 21 June 1979. The test consisted of a time-series of vertical profiles for solids concentration at five depths at bridge station #5. Sampling interval was 3 min. Test duration was 35 min. Sampling depths were 1.5, 4.0, 6.5, 9.0 and 11.5 ft (0.46, 1.2, 2.0, 2.7 and 3.51 m). Plots of the data are presented in Figures 17 through 21. The time-series in Figures 18 and 20 are incomplete and the sampling interval was 3 rather than 2 min because not enough sample bottles were available from the plant's laboratory on that day.

Process data pertinent to the Flow Pattern/Solids Distribution Test and the Weir-Wall Solids Test are presented in Table 3. Backup laboratory data were not available for the Dispersion Test day.

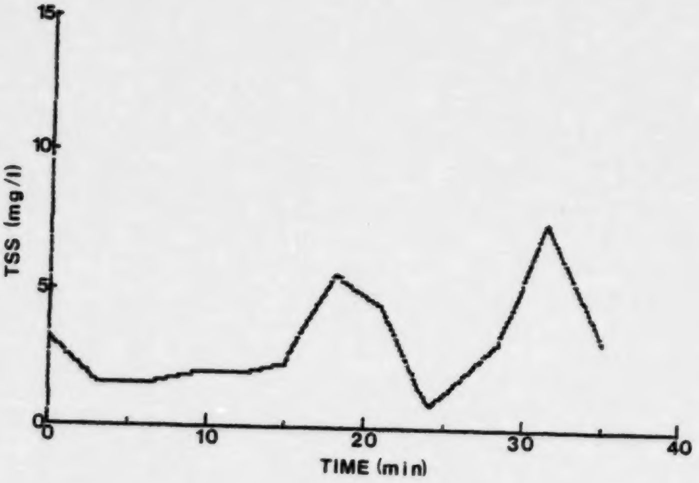


Figure 17. Weir-Wall Solids Concentration versus Time at a depth of 1.5 ft (0.46 m), Albuquerque secondary clarifier #1, station 5, 21 June 1979.

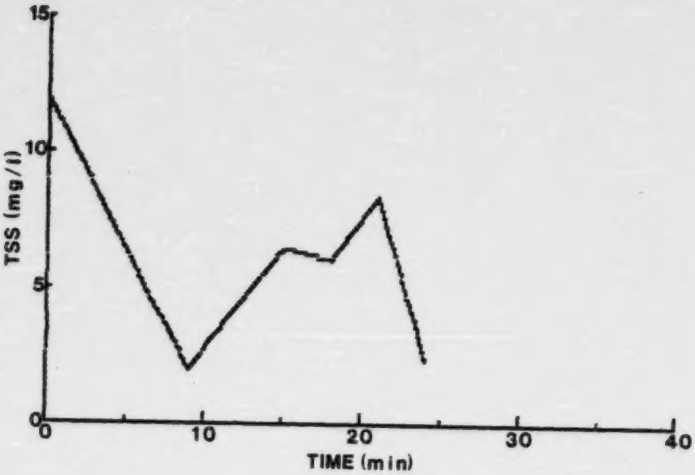


Figure 18. Weir-Wall Solids Concentration versus Time at a depth of 4.0 ft (1.2 m), Albuquerque secondary clarifier #1, station 5, 21 June 1979.

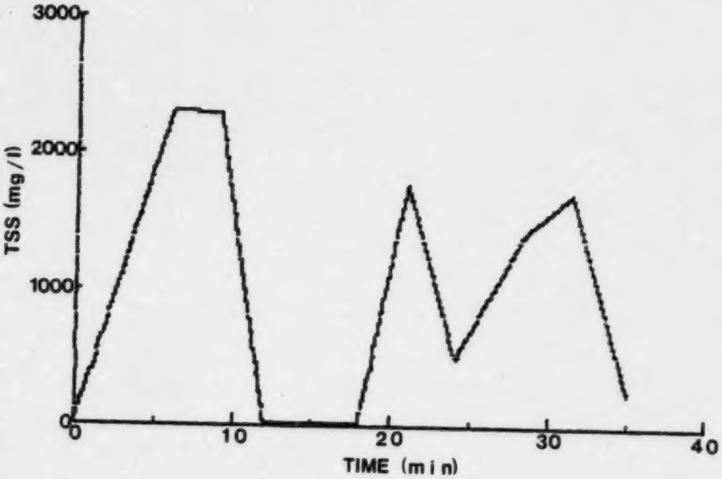


Figure 19. Weir-Wall Solids Concentration versus Time at a depth of 6.5 ft (2.0 m), Albuquerque secondary clarifier #1, station 5, 21 June 1979.

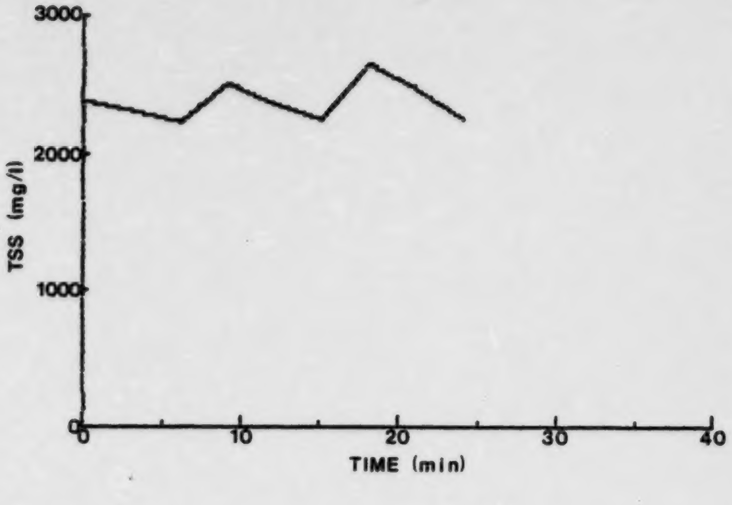


Figure 20. Weir-Wall Solids Concentration versus Time at a depth of 9.0 ft (2.7 m), Albuquerque secondary clarifier #1, station 5, 21 June 1979.

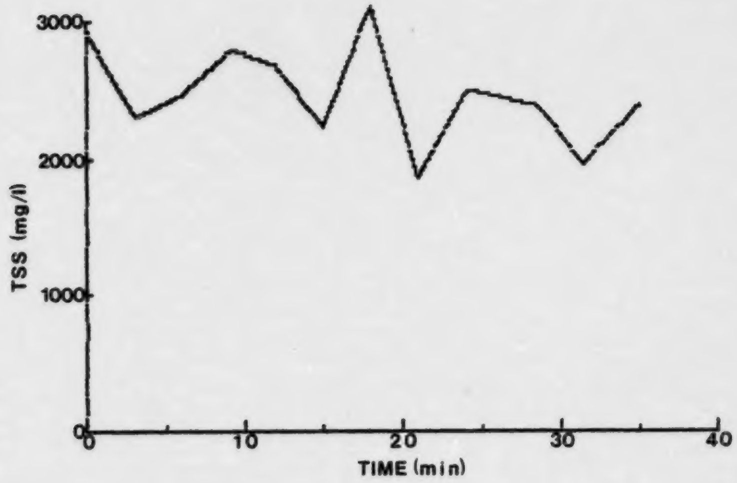


Figure 21. Weir-Wall Solids Concentration versus Time at a depth of 11.5 ft (3.51 m), Albuquerque secondary clarifier #1, station 5, 21 June 1979.

TABLE 3. PROCESS DATA ON THE TEST CLARIFIER, ALBUQUERQUE, NM, 21 JUNE 1979

MLTSS @ 1015	2150 mg/l
MLTSS @ 1500	2450 mg/l
Clar. #1 Eff. TSS @ 1015	7.2 mg/l
Clar. #1 Eff. TSS @ 1500	4.8 mg/l

Unstirred settling test @ 1530

Time (min)	Settled Sludge Volume	
0	1000	
5	550	
10	450	
15	380	
20	340	
25	330	
30	270	SVI = 110
40	250	
50	240	
60	240	

Discussion of the Albuquerque Test Results--

As background to this site's study, operators had observed that solids often overflowed the peripheral weirs more than the cantilevered inner weir troughs. During the study, the sludge was, in the operators' terminology, "in an early stage of filamentous bulking". Thus, the results may not be typical of normal conditions at Albuquerque.

The dispersion data are unremarkable to this investigator. The flow patterns exhibit a relatively thick forward flow layer with some imbalance in riser pipe draft. The solids distribution differs from those which will be presented for other center feed circular clarifiers.

The Weir-Wall Solids Test was inconclusive. As was explained in an earlier section, a "solids wave" phenomenon was expected, such as that illustrated in Figure 5. The "solids wave", now thought to be a solids jet effect, was measured at Stamford, CT directly in line with one inlet port. Because the jet effect was not recognized at the time, the location of the inlet port at Albuquerque was not noted. Also, the sludge condition was atypical. Thus, a "bulking sludge" condition may have acted to retard horizontal velocity within a layer of solids at approximately mixed liquor concentration.

It seems significant that the thick, diffuse blanket and the relatively thick, low velocity horizontal flow layer was associated with low effluent total suspended solids, as shown in Figure 17 and Table 3. In the more traditional facility design view, it may be argued that the good effluent quality is associated with the greater weir length made possible by the additional, cantilevered weir trough which provides two additional ranks of weirs. Data from the Albuquerque study neither confirm nor refute this argument. A second argument might be raised in support of the observation, frequently expressed by operators, that a high, but controlled blanket aids in the removal of small particles by a physical process of filtration. The author's opinion tends toward this belief, based on observations at Albuquerque and elsewhere[2,3]. Conversely, measurements at Oakland, Stamford and at another industrial site[4] suggest that a blanket very near the inlet baffle's lower limit promotes high horizontal velocity with accompanying turbulent eddies and consequent poor effluent quality. The difference in blanket height which determines whether filtration or energetic turbulence occurs may be only a foot or two. The shape of the solids contours near the feedwell in Figure 16 suggests that a "blowout" is imminent. It is speculated that a slightly lower blanket thickness at Albuquerque would have caused a deterioration in effluent quality because of increased turbulence.

Dallas County, Texas

Facility Description--

Only limited tests were completed on the clarifier at the Trinity River Authority's Ten Mile Creek Regional Wastewater Treatment Plant. This plant only has one clarifier which made a full evaluation impossible. However because of its record of excellent operation and its close proximity to the principal investigator's office, it was thought some inexpensive useful information could be obtained at this site.

The facility is an air activated sludge plant for the municipal wastewater from five cities, with a single secondary clarifier. A process schematic is shown as Figure 22.

The secondary clarifier, shown in Figure 23, is a 105 ft (32.0 m) diameter center feed, peripheral overflow unit with a 12 ft (3.7 m) sidewater depth. Maximum depth, at the center, is 16 ft (4.9 m). Design effluent rate is 6.8 mgd (25,700 m^3/d). The inlet feedwell has solid walls and is 15 ft (4.7 m) in diameter with a submerged depth of 7 ft (2.1 m). Sludge is removed by 10 riser pipes distributed along the scraper arms. Riser pipe rotation rate is 1 revolution per 34 min. There is no provision for scum removal. The clarifier has a single set of weirs at the periphery of the tank.

Total plant influent and secondary clarifier return sludge flows are measured by electromagnetic flowmeters. The waste sludge flowmeter has been bypassed because of insufficient capacity.

Hydraulic Test Results--

The Flow Pattern/Solids Distribution Test was made beginning at 1230 on 15 February 1979. A mixture of 900 ml Rhodamine WT and 2800 ml distilled water was injected at a rate of 16 ml/min at the point of discharge of one aeration basin. Three sample runs, which included 5 depths at each of 5 radial stations were made along the access bridge. The first run was begun at 1242 at the centermost station and completed at 1250 near the weir-wall. This and the two subsequent runs, at 17 min intervals, were begun just after passage of one riser pipe arm or the other.

Flow pattern data from the three sample sets are presented in Figures 24 through 26.

The distribution of suspended solids from the last sampling run is shown in Figure 27. Average clarifier effluent rate during the test was 6.790 mgd (25,700 m^3/d). This is equivalent to a surface area overflow rate of 784 gpd/sq ft (31.99 $m^3/m^2 \cdot d$).

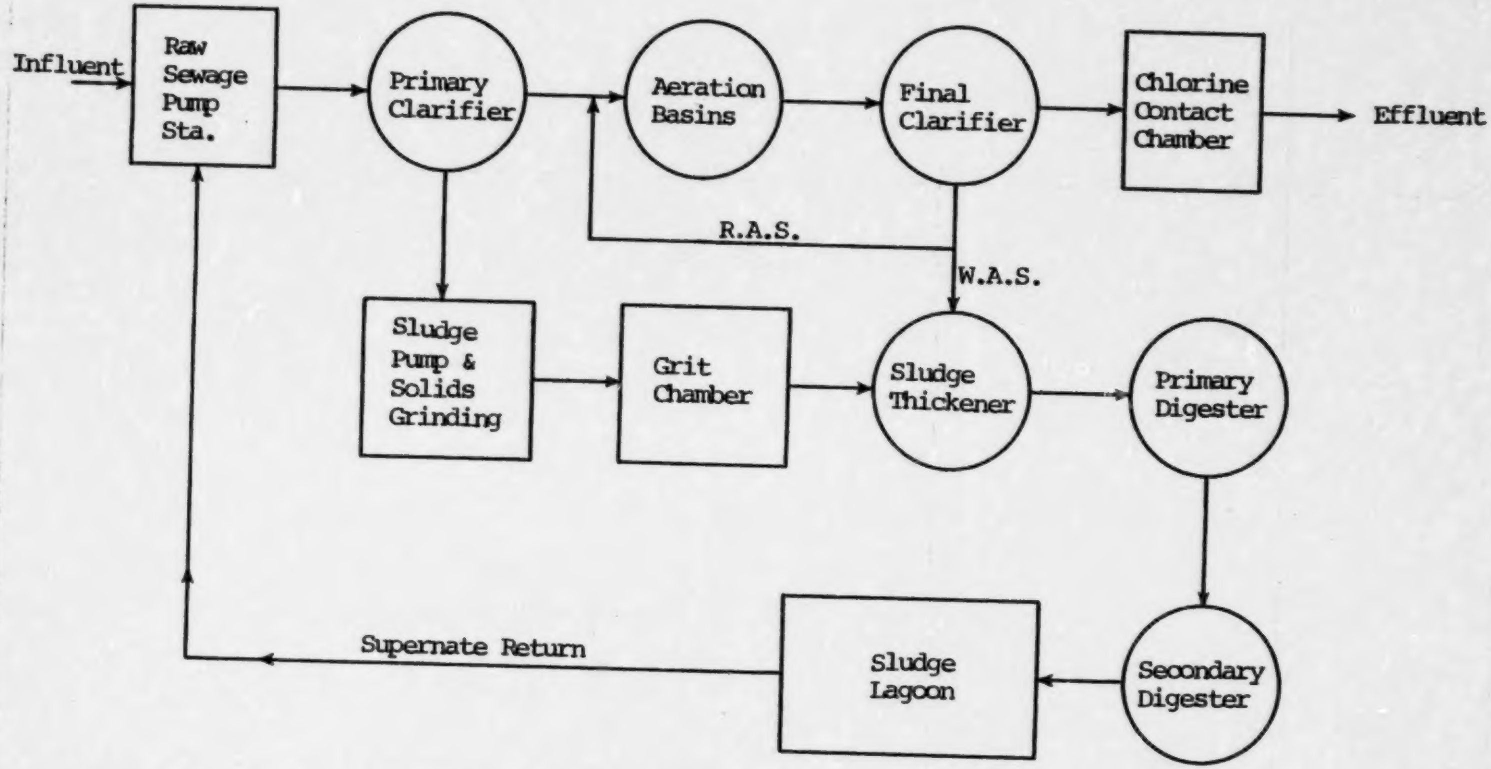
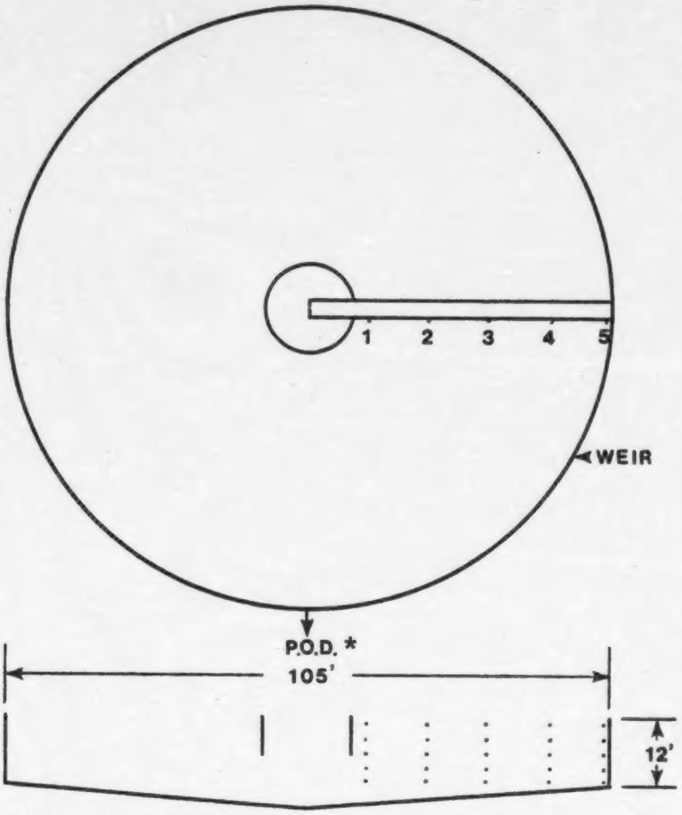

Influent
Raw Sewage Pump Sta.
Primary Clarifier
Aeration Basins
Final Clarifier
Chlorine Contact Chamber
Effluent
R.A.S.
W.A.S.
Sludge Pump & Solids Grinding
Grit Chamber
Sludge Thickener
Primary Digester
Secondary Digester
Sludge Lagoon
Supernate Return

Figure 22. Process schematic for the Ten Mile Creek wastewater treatment plant in Dallas County, TX.



*Point of Discharge

Figure 23. Plan and elevation of the Ten Mile Creek secondary clarifier.

Figure 24 indicates a deep horizontal flow which strikes the peripheral wall and begins upward movement toward the weirs. Figures 25 and 26 show a pattern of near-surface recirculation. Figure 27 suggests a turbulent flow pattern with a relatively low concentration solids distribution across the entire surface.

Only limited process data, Table 4, are presented for the day of this test.

Discussion of the Dallas County, Ten Mile Creek Results--

The flow pattern in this center feed circular clarifier exhibited what has now been recognized as one of several different characteristics seen in these units. Under the measured conditions, flows progressed rapidly to the peripheral wall, then turned sharply upward toward the overflow weir. A portion of the flow rebounded into the central surface area of the tank. High concentration solids, those above 729 mg/l (27 squared),

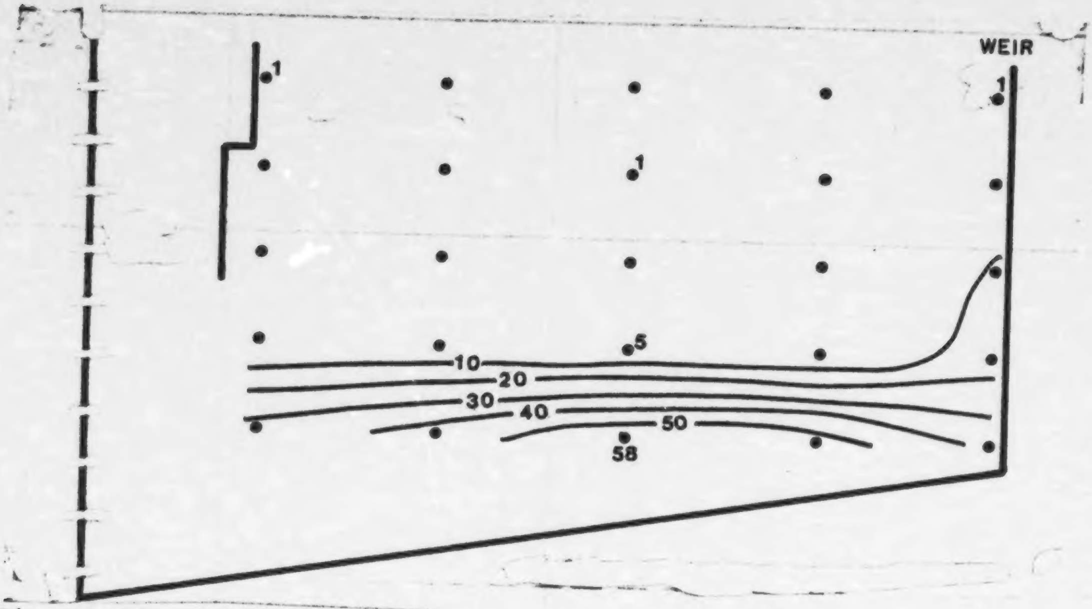


Figure 24. Radial distribution of the dye concentration in the Dallas County Ten Mile Creek secondary clarifier, 16 min after the start of continuous dye injection, 15 February 1979.

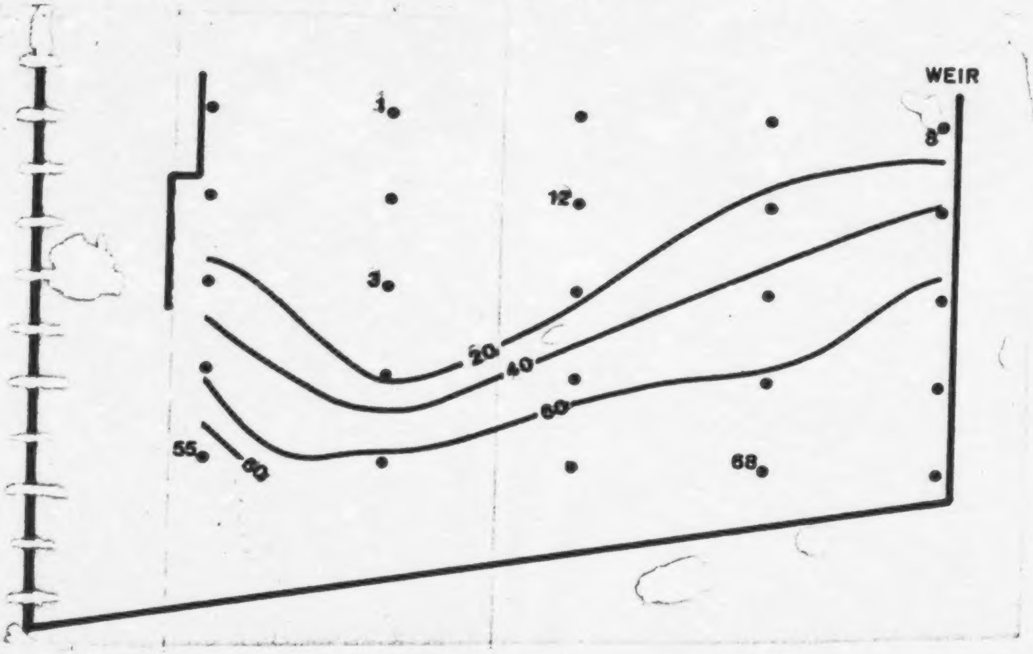


Figure 25. Radial distribution of the dye concentration in the Dallas County Ten Mile Creek secondary clarifier, 33 min after the start of continuous dye injection, 15 February 1979.

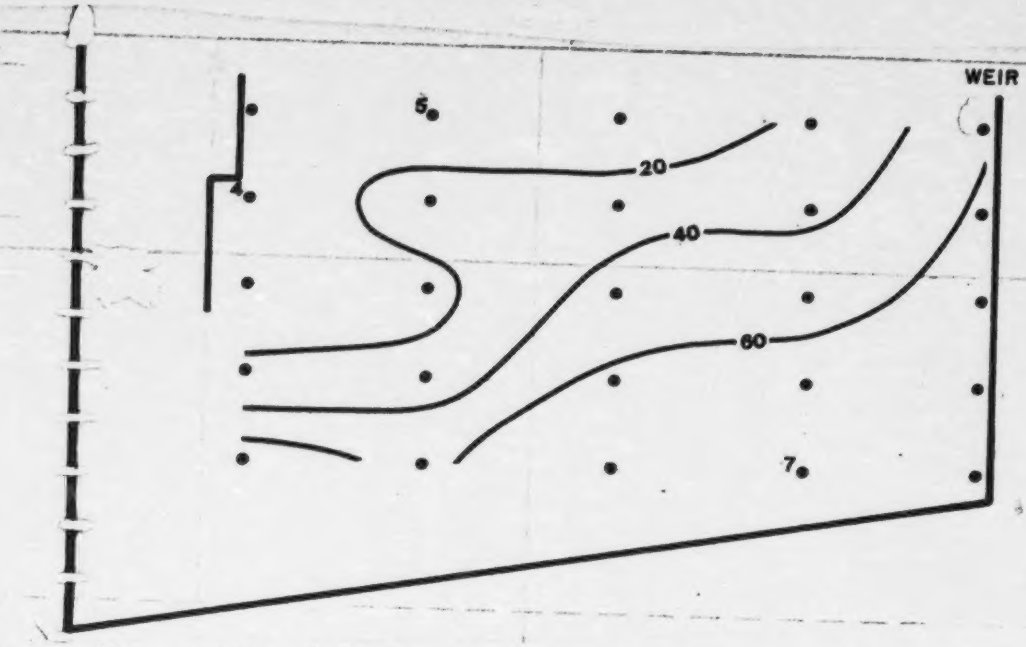


Figure 26. Radial distribution of the dye concentration in the Dallas County Ten Mile Creek secondary clarifier, 50 min after the start of continuous dye injection, 15 February 1979.

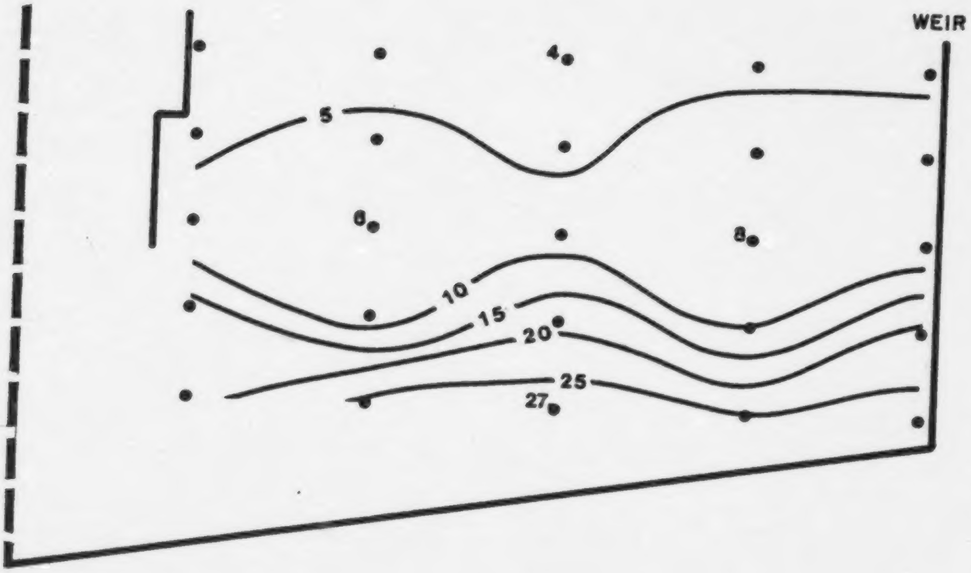


Figure 27. Radial distribution of the square-root of total suspended solids in the Dallas County Ten Mile Creek secondary clarifier, 15 February 1979.

TABLE 4. PROCESS DATA ON THE TEN MILE CREEK SECONDARY, DALLAS COUNTY, TEXAS, 15 February 1979

	Aerator #1	Aerator #2
MLTSS	1380 mg/1	950 mg/1
SVI	72	78
Effluent TSS composite from 0700, 15 Feb to 0700 16 Feb------------	16 mg/1	

---

are confined to a region beneath the lowest sampling points. The shape of the solids contours in Figure 27 suggests a relatively turbulent environment.

Effluent total suspended solids values are consistently lower than permit values at this plant despite an underflow which is higher than normally practiced elsewhere.

Holly Hill, Florida

Facility Description--

Extensive hydraulic studies and modifications were completed at the City of Holly Hill's municipal wastewater treatment facility. This plant uses an activated sludge process with mechanical aerators, the schematic of which is shown in Figure 28. Two aeration basins are provided that combine and feed both secondary clarifiers.

There are two 65 ft (19.8 m) long, 16 ft (4.9 m) wide rectangular secondaries as shown in Figure 29. Sidewater depth is 9 ft (2.7 m). Design effluent rate for each unit is 0.6 mgd (2,300 m^3/d). The clarifiers, each with four 12 in (30.5 cm) square inlets, were fitted with redwood baffles, 3 ft (0.9 m) downstream of the inlet ports; the baffles extended from side wall to side wall, from the surface to a depth of 3 ft (0.9 m). Sludge is moved by a chain and flight mechanism toward a sump at the inlet end of the tanks.

Scum is removed periodically, as necessary, by hand rotating a scum trough. Scum is blended with the return sludge and recirculated to the aeration tanks.

Four weir troughs, each 7.5 ft (2.29 m) long, provide a total weir length of 64 ft (19.5 m), at the downstream end of each clarifier. Weirs are straight-edged, not V-notched.

Recording, totalizing flowmeters are provided for total plant effluent rate and for total underflow rate from both secondaries. Underflow balance is achieved by adjustment of telescoping valves, after observation of blanket position. There is no provision for balancing flow to the two clarifiers except by effluent weir adjustment. For purposes of this study, a rectangular weir and level guage were installed in the test clarifier's discharge trough. This temporary guage and the plant's total flow meter were calibrated by dye dilution. Approximate unit-to-unit balance was achieved by cut-and-try weir adjustment during peak flow hours.

General Study Description--

An extensive evaluation was made of the clarifiers at Holly Hill including initial hydraulic tests and two modifications, with subsequent hydraulic tests and performance evaluations to quantify any improvement in the clarifier hydraulic characteristics. A more complete evaluation was made at this site because a separate research grant was awarded to the City of Holly Hill by USEPA to investigate their clarifiers. At the beginning of the evaluations, the principal investigator had some preconceived notions on what the hydraulic characteristics were and how they could be modified to improve performance. As the investigation

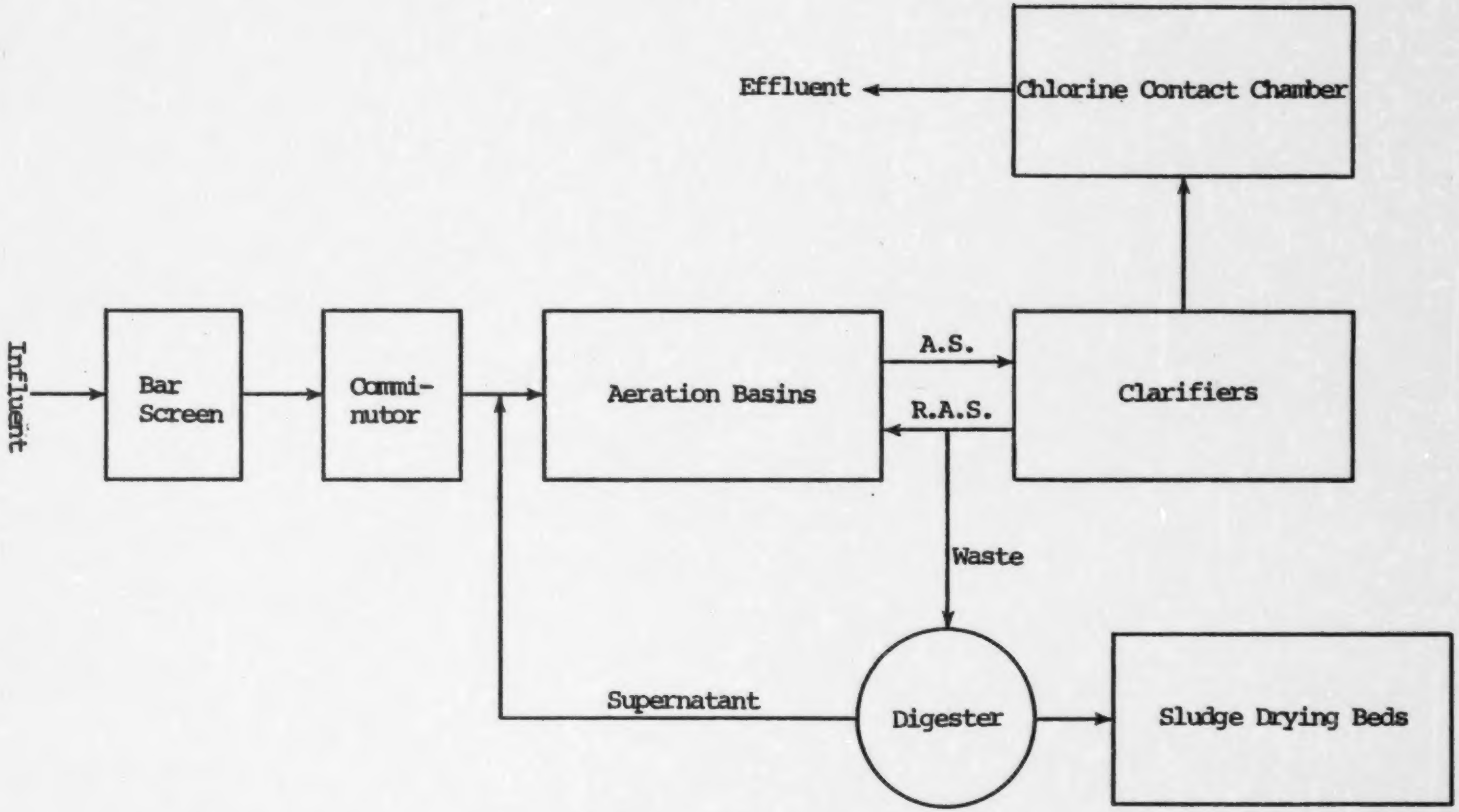

Effluent
Chlorine Contact Chamber
Influent
Bar Screen
Commi-nutor
Aeration Basins
A.S.
R.A.S.
Clarifiers
Waste
Supernatant
Digester
Sludge Drying Beds

Figure 28. Process schematic for the Holly Hill, FL wastewater treatment plant.

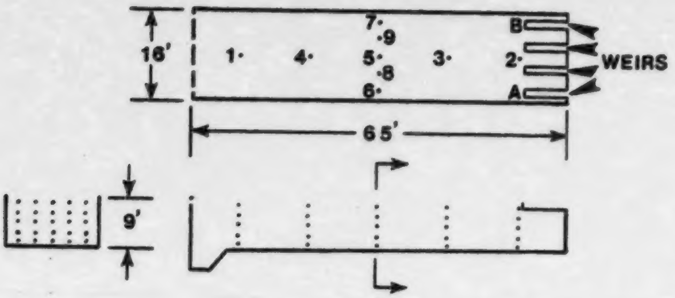


Figure 29. Plan and elevation of the Holly Hill, FL south (test) clarifier.

proceeded, the factors first thought to be important were not found to be as critical as others.

It was expected that measurements of the clarifier's flow patterns would reveal the need for a modified inlet structure that would improve the vertical distribution of mixed liquor in the inlet region with a subsequent decrease in effluent total suspended solids. Some improvement was noted from baffling alone, but not nearly to the extent expected. As a side issue, it was decided to utilize about 1000 gal (4 m^3) of available raw sewage inlet channel to the aeration basin as a storage device to smooth the hydraulic effect of intermittent lift station operations.

Because only the total plant discharge is normally measured and recorded at Holly Hill, a sharp crested rectangular weir and recording level guage were installed to measure flows from the test (south) clarifier alone. Calibration of the plant's flow meter and the south clarifier's level gauge was attempted several times using the dye dilution method, but the calibrations were not satisfactory because of the rapidly varying plant throughflow rates.

The effluents from the modified and un-modified clarifiers were separated by a temporary wooden structure in the discharge trough to allow separate comparative sampling. The primary comparative measurement was of total suspended solids in the effluents of the 2 clarifiers based on 24 hour composite samples when automatic samplers were working, or by 18 hour composites retrieved by hand from the center of each clarifier's weir region, when samplers were not functioning properly.

On days of intensive hydraulic testing, detailed laboratory results were reported as shown in Appendix A. During the comparative phases of the study, the following data was collected daily:

Date
Total flow (24 hour average)
Effluent TSS from control clarifier
Effluent TSS from modified clarifier
MLTSS
SVI
MCRT
Oxygen uptake
Blanket depth - control clarifier
Blanket depth - modified clarifier
Level guage record for the south clarifier's discharge
Percent return flow

Whether or not the storage gate was in use was reported or could (with a few exceptions) be determined from level guage recordings submitted. These data are presented in tabular form in Appendix B and graphically, in Appendix C.

Analyses of flow pattern data were accomplished in the field to allow successive modifications and immediate evaluation of the hydraulic effects of the changes. In this way, the inlet ports were balanced, using cross-sectional flow contours at mid-tank; and fine-tuning of reaction baffle configurations was accomplished, by a combination of longitudinal and cross-section contour flow pattern charts.

The sequence of the experimental program is pertinent to interpretation of the results. The study began with a series of hydraulic tests to discover the existing hydraulic regime within the test clarifier during late February 1979. Initial baffle modifications were completed by 6 March, but heavy rains interrupted the "fine-tuning" of the new inlet reaction baffles. A week later, adjustment was attempted using visual, or surface, dye and turbidity observations, but subsequent effluent TSS measurements indicated only marginal advantage of the test baffling scheme over the original scheme, in the control clarifier alongside. It should be noted that analysis began with data collected on 12 March, following initial visual observations.

A second measurement series was undertaken during the period 26-30 March. This series included longitudinal and cross-sectional flow pattern tests following each of several "tuning" modifications; in effect, this was a cut-and-try procedure.

By late May, a modest gain in average effluent performance had been noted, but floc clouds could still be seen occasionally at the weir end of the test clarifier. In order to further enhance vertical distribution and minimize the floc clouds, a plate was added to the bottom side of the reaction baffles on 1 June. This is the final configuration adopted. Data analysis of the first and final baffle configurations are separate.

Because of the high short term and long term flow variability at the Holly Hill plant and because storage versus no-storage conditions as well as the effectiveness of baffle modification were under investigation, the data collection period included in the analysis was lengthy, 267 days from 12 March to 3 December 1979.

Use of the storage gate, which was quite important in understanding the data, was to be on a week on, week off basis. This was not always possible, mainly because the storage scheme could not be used during very high flows following wet weather. But a reasonable number of alternating on-off conditions were included throughout the 267 day study period.

Because raw sewage enters the plant entirely by constant speed, intermittent lift stations which are in no way synchronized with each other, short term flow variability is quite high. In one typical 60 min period, the discharge from one of the secondaries exhibited a peak value of 0.98 mgd (3710 m^3/d) and a low flow of 0.35 mgd (1320 m^3/d). This is a ratio of 2.8:1. The record of that hour's measurements, with a data interval of 1 minute, is shown in Figure 30. The storage gate was in place at the time. This peakiness is superimposed on the small system's normally high diurnal flow changes and a wet/dry weather flow ratio of nearly 3:1. The plant, rated hydraulically at 1.2 mgd (4500 m^3/d) receives raw sewage from lift stations, the pumps of which have ratings which total 12 mgd (45,000 m^3/d). Actual maximum flow will, of course, be less than 12.0 mgd because of force main back pressure.

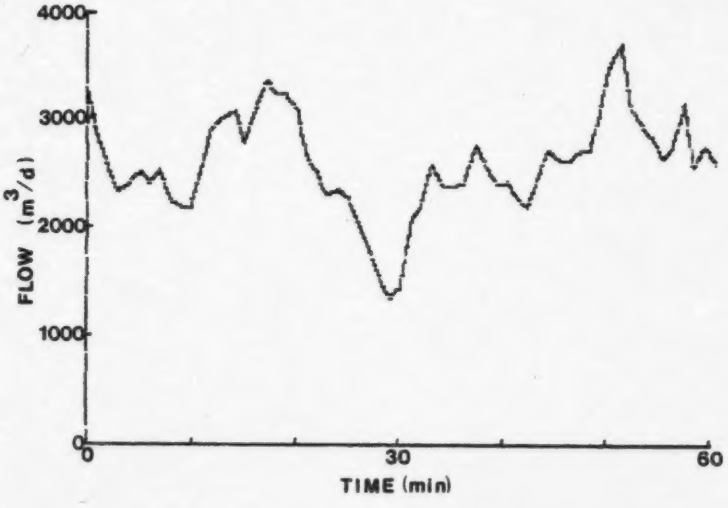


Figure 30. Holly Hill south clarifier discharge rate during one hour of peak flows, 3 March 1979. Storage gate was in place.

Flow, gate position, effluent quality and pertinent process control data are listed in both tabular and graphic form in Appendices B and C. Days of storage or no-storage are also noted. Because of the relatively high fluctuations of most parameters, a casual scan of the data does not give a clear indication of cause and effect. The investigators have therefore resorted to data averages in an attempt to correlate performance with the modifications made.

Initial Hydraulic Test Results--

The south clarifier was selected as the candidate for detailed tests and modification because it was possible to install a rectangular weir and recording level guage in its discharge channel, upstream and separate from the discharge of the north clarifier.

Weirs were leveled on the still surface of each clarifier after shutdown. Since both units could not be shut down simultaneously, it was hoped that balance between units would result from careful leveling of each, in turn.

A bulk release Multi-Point Dispersion Test was conducted on 28 February 1979, with samples retrieved at the two weirs nearest the side walls of each clarifier, in order to test side-to-side and unit-to-unit balance at an average plant flow rate during the test of 1.7 mgd (6300 m^3/d). Physical data pertinent to this dispersion test is presented in Table 5.

TABLE 5. PHYSICAL DATA PERTINENT TO THE DISPERSION TEST ON THE HOLLY HILL SECONDARY CLARIFIERS, 28 FEBRUARY 1979

Background fluorescence = 1.7 ppb
Tank volume = 70,000 gal
Average effluent rate during test = 0.83 mgd
Average underflow rate during test = 0.23 mgd
Retention time based on influent rate, T_O = 94.5 min
30 ml of dye were used in test clarifier only
Flash mix fluorescence, C_O = 113.2 ppb

Weir Station*	Relative Dye Mass Overflowing Weir Station	Median Retention Time for This Test (min)
A	1.352	53.2
B	1.376	51.6
C	1.391	52.4
D	1.360	53.7

* Stations A and B are the outer weir troughs of the south, or test clarifier. Stations C and D are the outer weir troughs of the north, or control clarifier. Stations B and C are the weirs nearest the common wall separating the two rectangular units.

The four dispersion curves, almost identical in appearance, are shown as Figures 31 through 34.

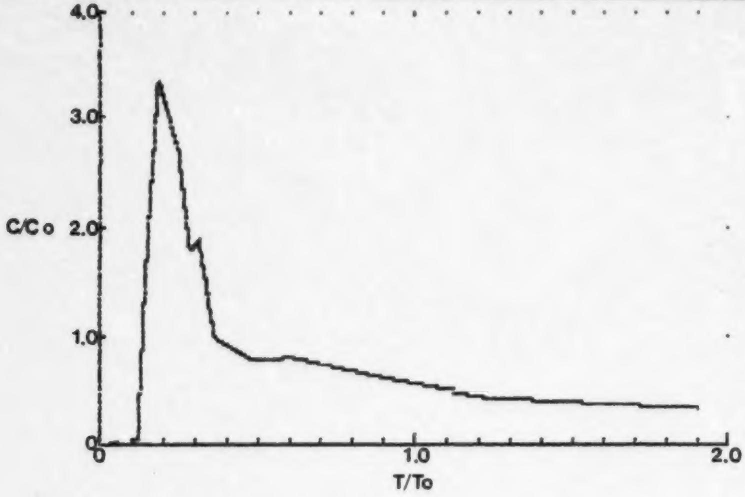


Figure 31. Results of the Multi-Point Dispersion Test for the Holly Hill south clarifier, weir station A, 28 February 1979.

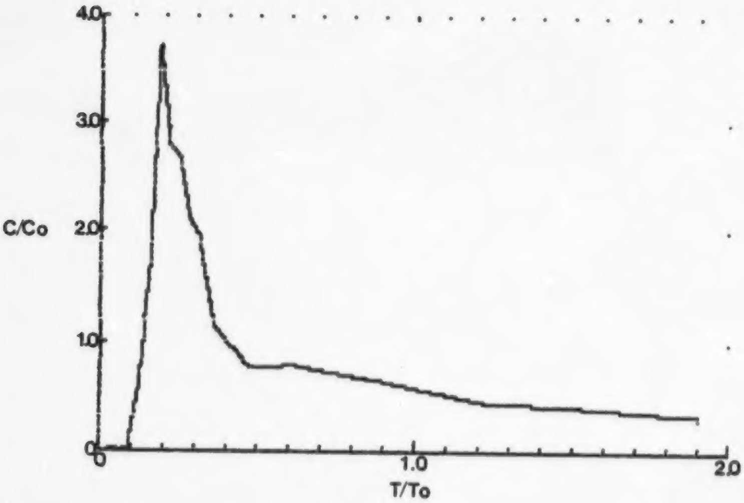


Figure 32. Results of the Multi-Point Dispersion Test for the Holly Hill south clarifier, weir station B, 28 February 1979.

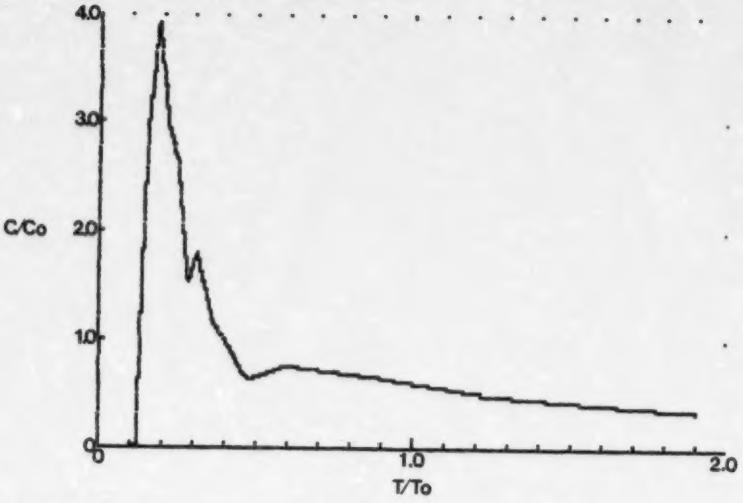


Figure 33. Results of the Multi-Point Dispersion Test for the Holly Hill north clarifier, weir station C, 28 February 1979.

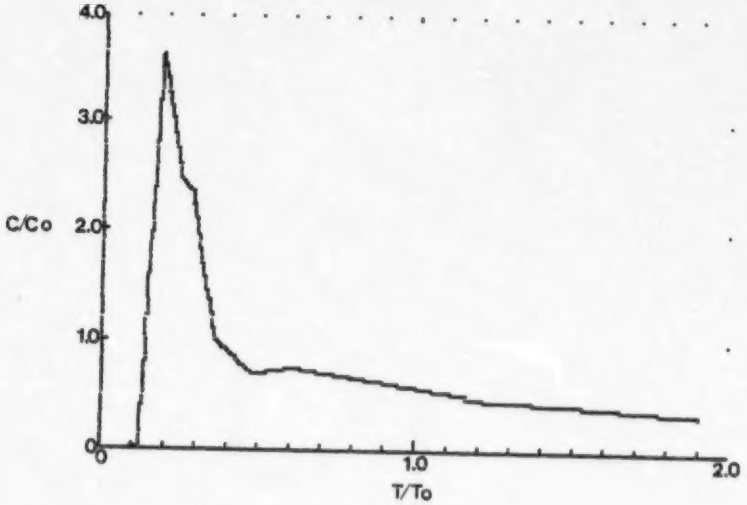


Figure 34. Results of the Multi-Point Dispersion Test for the Holly Hill north clarifier, weir station D, 28 February 1979.

If it is assumed that the dye was equally distributed at the inlets and the effective throughflow, or cross-sectional areas were the same then these data would suggest hydraulic balance within approximately 1.0%.

The Flow Pattern/Solids Distribution Test, shown as Figures 35 through 39, revealed the flow trajectories. The major flow route was downward along the inlet wall into the return sludge sump, along the top of the sludge blanket and upward toward the overflow weirs. A surface recirculation, or backeddy, was apparent in the dye plots and could also be observed visually by the movement of floc particles, near the surface, toward the inlet region. Figure 39 suggests that the flow regime prevents high concentrations of solids from being scraped all the way to the sludge sump; more concentrated solids are found about two-thirds of the way weirward along the tank bottom. Figure 37 best illustrates a relatively small leakage of mixed liquor through the original slotted inlet baffle, in the upper left-hand corner of the illustration.

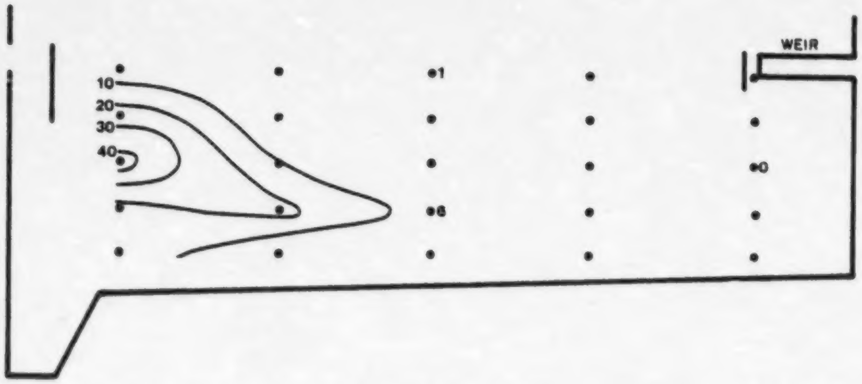


Figure 35. Distribution of the dye concentration in the central longitudinal section of the Holly Hill south clarifier, 7 min after the start of continuous dye injection, 1 March 1979.

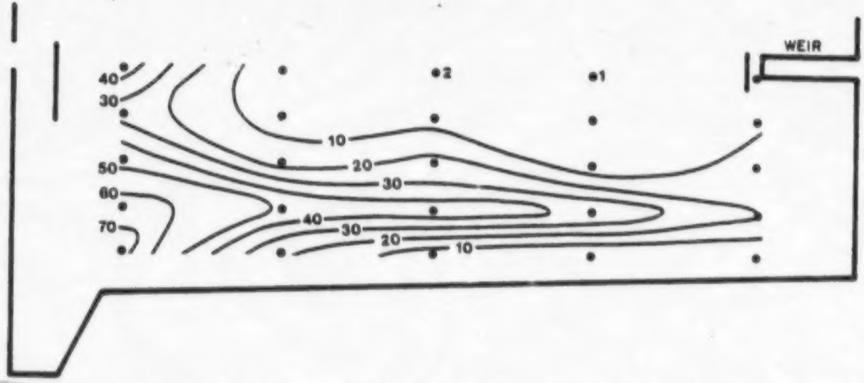


Figure 36. Distribution of the dye concentration in the central longitudinal section of the Holly Hill south clarifier, 15 min after the start of continuous dye injection, 1 March 1979.

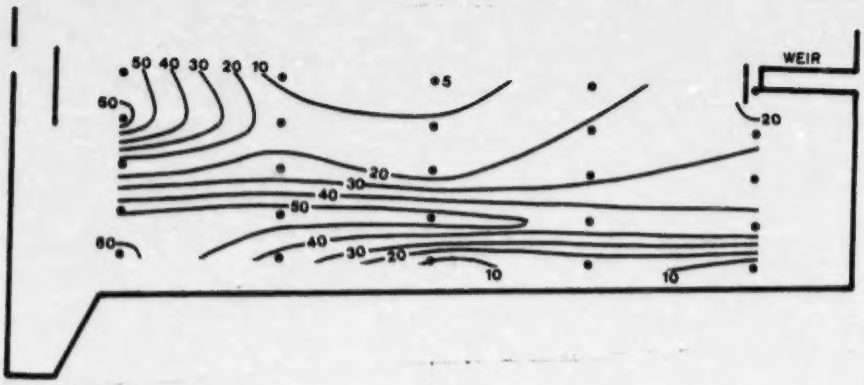


Figure 37. Distribution of the dye concentration in the central longitudinal section of the Holly Hill south clarifier, 23 min after the start of continuous dye injection, 1 March 1979.

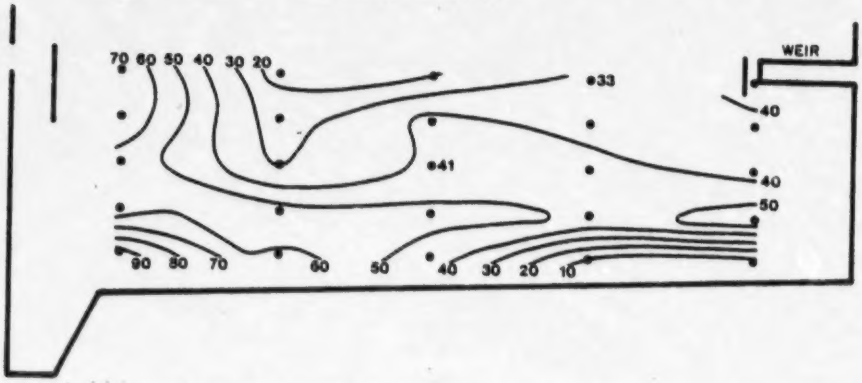


Figure 38. Distribution of the dye concentration in the central longitudinal section of the Holly Hill south clarifier, 31 min after the start of continuous dye injection, 1 March 1979.

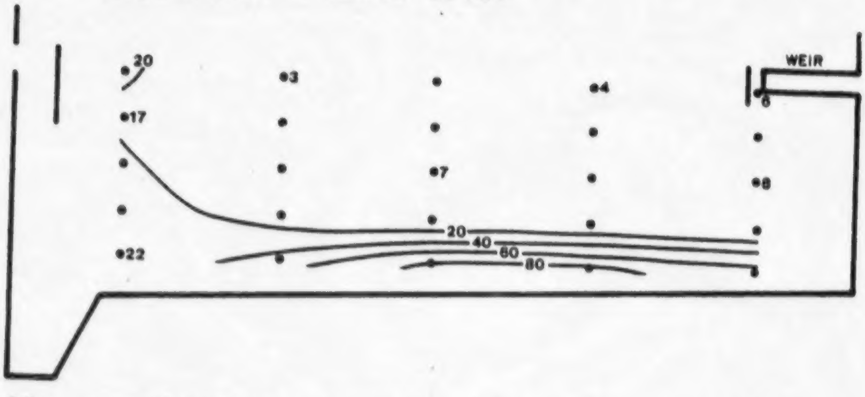


Figure 39. Longitudinal distribution of the square-root of total suspended solids in the Holly Hill south clarifier, 1 March 1979.

Immediately following these tests and the field analysis, it was decided to remove existing baffles and construct prototype reaction baffles to be placed immediately in front of the four inlet ports of the south clarifier. These modifications were completed within a few days. Figure 40 is a sketch of the new reaction baffles which were designed to hang on to the inlet wall. The prototypes were constructed of steel and three-eights inch plywood. The 5 holes in the baffle were intended to encourage approximately 20% forward flow of incoming mixed liquor.

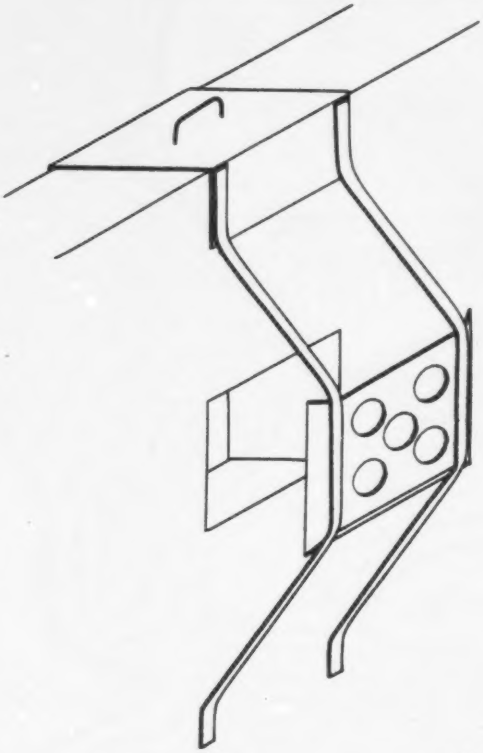


Figure 40. Sketch of one of the original four prototype reaction baffles constructed for the Holly Hill south clarifier.

The rain-interrupted project was resumed on 12 March, with the intention of "fine tuning" the inlet baffle configuration and making initial observations of their effectiveness. This was to have been accomplished by visual observations of the comparative progress of dye through both clarifiers and turbidity at the weir end of both units. Baffle holes were found to be a maintenance problem because they tended to catch rags. Flow through the four clarifier inlet ports was also seen to be unbalanced, with progressively greater flow entering downstream ports from the mixed liquor channel. Reverse flow may have actually been occurring occasionally at the first port. An attempt at inlet balance by selective partial plugging of the baffle holes was unsuccessful. Finally, all holes were blanked off and baffles were offset laterally from the inlet ports to the position where maximum reaction was visually apparent. Frequent visual judgement between flow overflowing the weirs of the modified and unmodified clarifiers, for a period of 6 peak flow hours, indicated consistently lower turbidity in the vicinity of the newly baffled south clarifier's weirs.

Evaluation of Initial Modifications--

Following a week of comparative effluent TSS measurements, the modified clarifier had no better performance than the control. (See Appendix B, days 1-7.) Thus, a second series of hydraulic tests and modifications was undertaken during the week of 26 March. It should be noted that approximate flow equality between north and south clarifiers was checked as carefully as possible on each test day. Balance appeared to be within a few percent in each case during peak flow hours. The extreme flow variation at this site made accurate flow checks nearly impossible.

To evaluate the initial modifications, a single-snapshot Flow Pattern Test was performed in place in the south (test) clarifier. Distribution of the dye concentration from this test is presented in Figure 41. It is apparent that vertical flow distribution has been improved, but that the flow favors the right-hand wall of the clarifier.

Additional Modifications--

In an attempt to improve the lateral flow distribution in the clarifier, standard size concrete building blocks were placed in the mixed liquor channel between the inlet ports to gradually decrease the channel cross-section. This modification is illustrated in Figure 42.

A single-snapshot Flow Pattern Test was performed following this modification to determine what changes had occurred in the hydraulic characteristics. The result of this test is shown in Figure 43. A similar broad front of dye concentration is seen in the longitudinal section, but the dye concentrations in the lateral section indicated that flow preference had shifted to the left-hand wall.

Further visual observation near the inlets revealed that a surface cross-current from right to left was being induced by the angled reaction baffle "wings". In order to isolate the four inlets, three removable plywood separators were constructed and installed between the ports as shown in Figure 44.

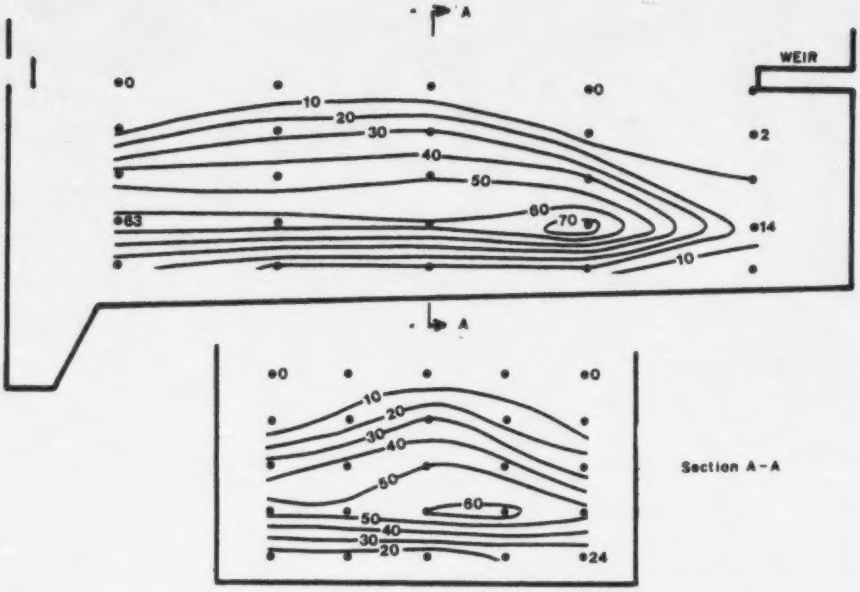


Figure 41. Distribution of the dye concentration in the Holly Hill south clarifier with the initial modifications, 15 min after the start of continuous dye injection, 26 March 1979.

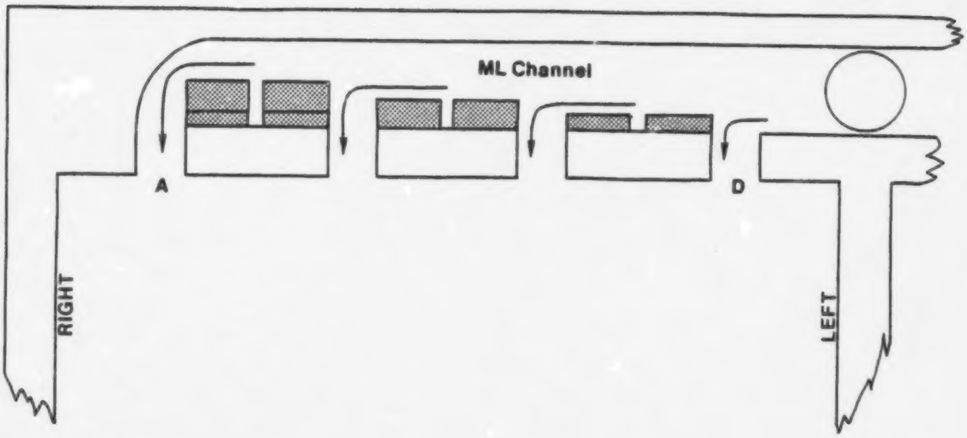


Figure 42. Plan view of the inlet end of the Holly Hill south (test) clarifier. Concrete block "flow equalizers" are shaded. Prior to placement of the blocks, the inlet port marked A received the greatest flow; the port marked D received almost none.

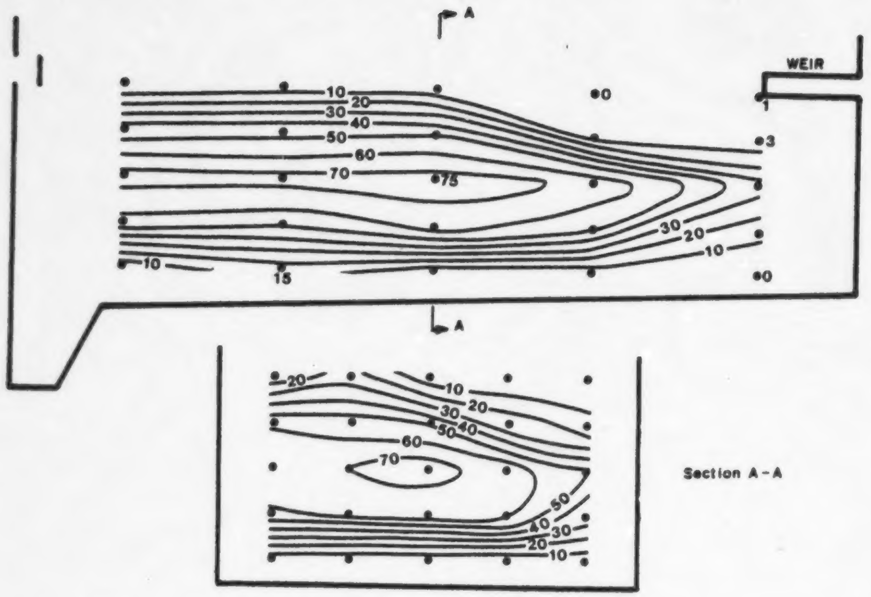


Figure 43. Distribution of the dye concentration in the Holly Hill south clarifier, 15 min after the start of continuous dye injection, 27 March 1979. Reaction baffles and flow port equalizing blocks are in place.

A single-snapshot Flow Pattern Test was completed following these modifications on 28 March 1979 in order to evaluate the hydraulic effects of the reaction baffles, the inlet-channel flow equalizing blocks and the inlet-port separators. Figure 45 shows the results of this test under a normal low blanket condition.

On the next day, 29 March 1979, effluent turbidity appeared higher. Measurements by optical sensor showed a higher blanket. The single-shapshot Flow Pattern Test was repeated with the result shown in Figure 46. Analysis was also made for total suspended solids in the longitudinal section. The Solids Distribution plot is presented in Figure 47. Reaction baffles, inlet-channel flow equalizing blocks and the inlet port separators were all in place.

At this stage of the study, it was believed that almost ideal plug-flow conditions had been established by the inlet modifications although a high blanket condition seemed to degrade performance. In retrospect, there are at least two phenomena which may have influenced the results up to this date.

1. Although average plant flows, indicated by totalizer readings, were comparable on the various flow pattern test days,

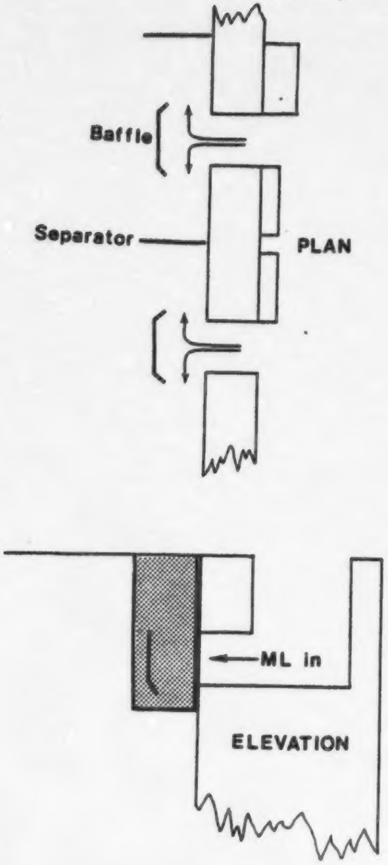


Figure 44. Sketch showing the position of reaction baffles and separators (shaded) in the Holly Hill south clarifier.

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the Holly Hill system is subject to radical short-term flow variations. Thus, what was perceived as an improved throughflow pattern might actually have resulted from a temporarily lower plant flow rate.

2. The longitudinal distributions of solids from the Flow Pattern/Solids Distribution Tests of 1 March and 29 March 1979, Figures 39 and 47 respectively, were quite different. The solids were much more diffuse during the latter test. It is unknown whether the difference resulted from changes in mixed liquor settling quality, from dynamic mixing due to high amplitude flow rate changes, from a greater mass of solids in the tank or from the inlet modifications which had been made.

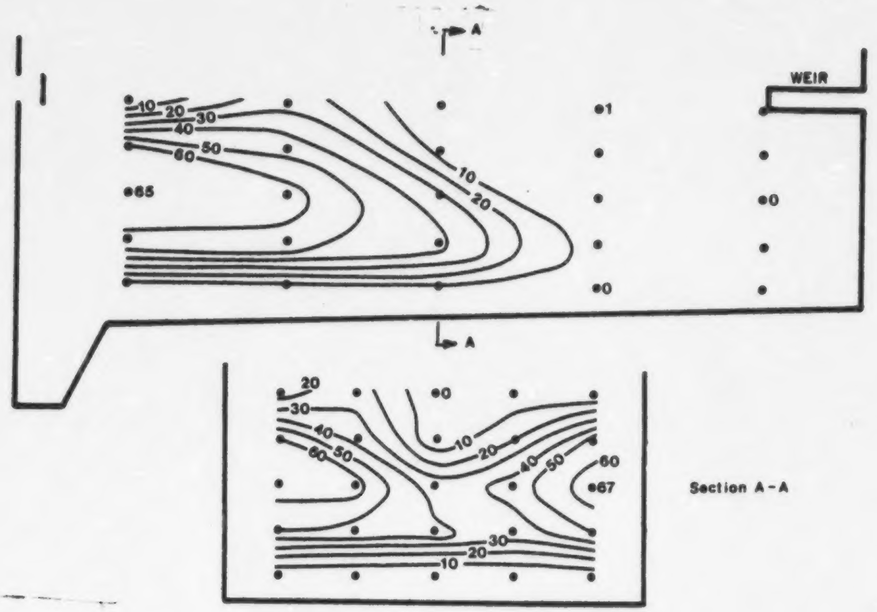


Figure 45. Longitudinal and cross-sectional distributions of the dye concentrations in the Holly Hill south clarifier, 15 min after the start of continuous dye injection, 28 March 1979.

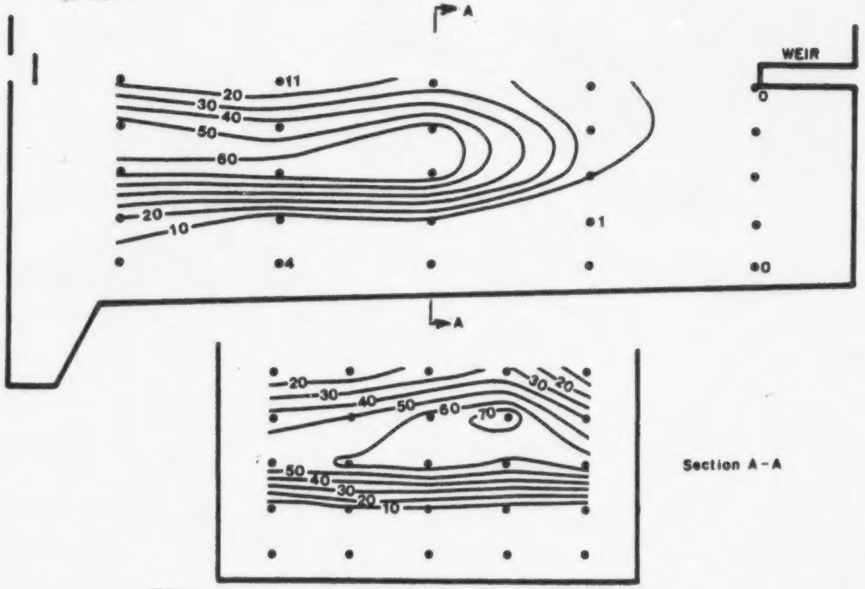


Figure 46. Longitudinal and cross-sectional distributions of the dye concentrations in the Holly Hill south clarifier, 17 min after the start of continuous dye injection, 29 March 1979.

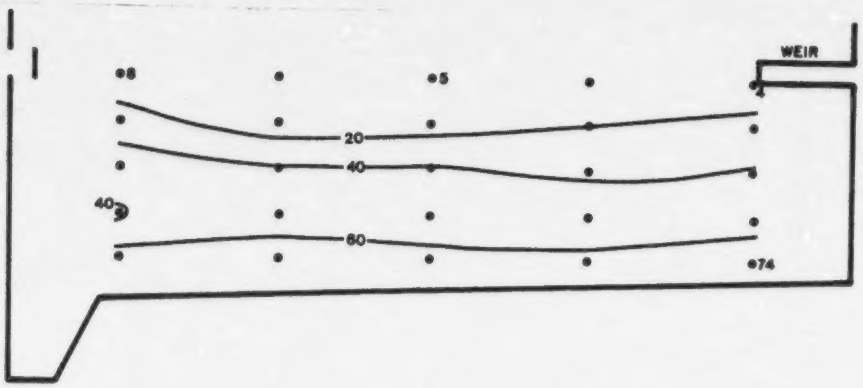


Figure 47. Longitudinal distribution of the square-root of total suspended solids in the Holly Hill south clarifier, 29 March 1979.

Final Modification--

The dye tests had suggested that almost ideal hydraulic characteristics had been developed in the modified south clarifier at Holly Hill. Results from the parallel performance tests and visual observations by the plant personnel indicated that possible further improvements in the inlet conditions could be made. A decision was made, on 1 June 1979, to add bottom plates to the reaction baffles as shown in Figure 48. This change was intended to minimize inlet region density currents which were thought to be still flowing downward, across the sludge blanket to the back wall, causing excessive effluent solids.

Final Hydraulic Tests--

With several months of improved performance, a final Flow Pattern/Solids Distribution Test series was completed on 28 August 1979. The results of these tests are shown in Figures 49 through 52.

The results from these tests were very surprising in that the flow patterns and the solids distribution were almost identical to those measured before any modifications had been completed. The only significant difference observed was that the sludge trough was no longer being severely scoured.

The results of a Multi-Point Dispersion Test on 29 August 1979 were equally surprising. The median retention time appears to have decreased as shown in Table 6. The shapes of the dispersion curves, Figures 53 through 56 are hardly distinguishable from those of the 28 February test, Figures 31 through 34.

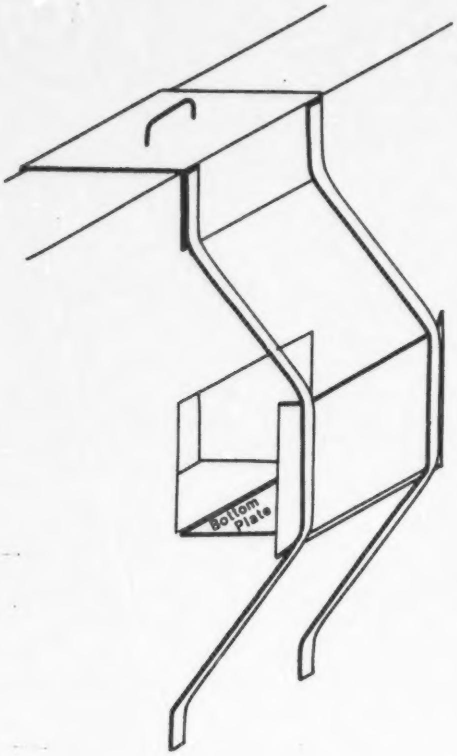


Figure 48. Holly Hill reaction baffle with final modification of a bottom plate, 1 June 1979.

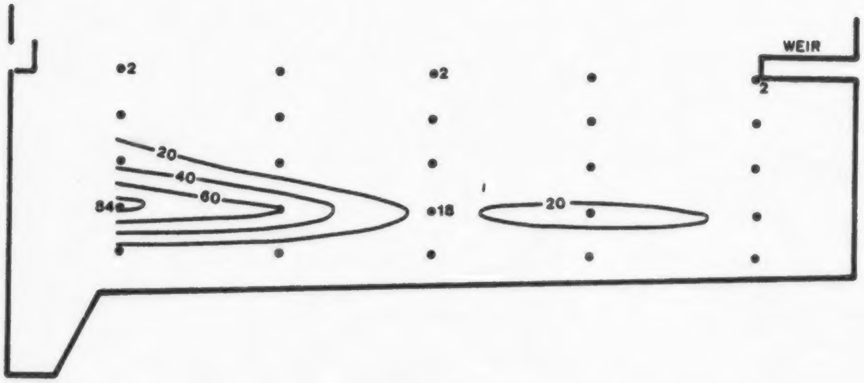


Figure 49. Longitudinal distribution of the dye concentrations in the Holly Hill south clarifier, 7 min after the start of continuous dye injection, 28 August 1979. Final modifications are in place.

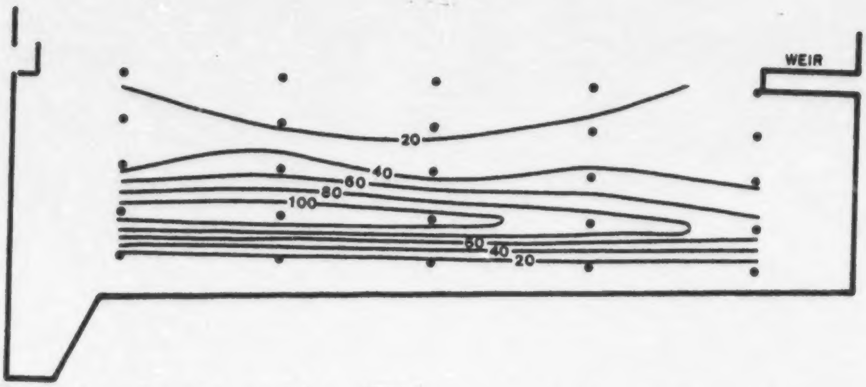


Figure 50. Longitudinal distribution of the dye concentrations in the Holly Hill south clarifier, 15 min after the start of continuous dye injection, 28 August 1979. Final modifications are in place.

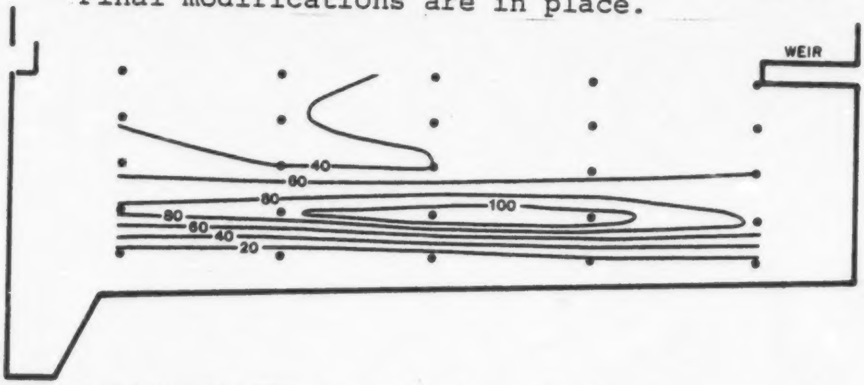


Figure 51. Longitudinal distribution of the dye concentrations in the Holly Hill south clarifier, 23 min after the start of continuous dye injection, 28 August 1979. Final Modifications are in place.

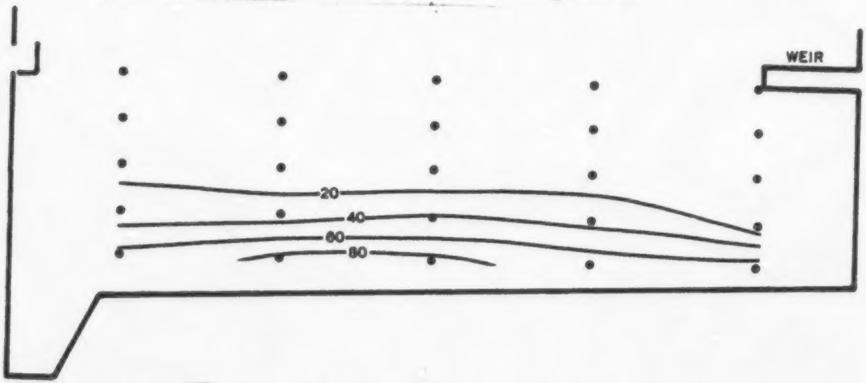


Figure 52. Longitudinal distribution of the square-root of total suspended solids in the Holly Hill south clarifier, 28 August 1979. Final modifications are in place.

TABLE 6. PHYSICAL DATA PERTINENT TO THE DISPERSION TEST ON HOLLY HILL SECONDARY CLARIFIERS, 29 AUGUST 1979

Background fluorescence = 1.7 ppb
Tank volume = 70,000 gal
Average effluent rate during test = 0.83 mgd
Average underflow rate during test = 0.21 mgd
Retention time based on influent rate, T_O = 96.4 min
40 ml of dye were used in test clarifier only
Flash mix fluorescence, C_O = 150.9 ppb

Weir Station*	Relative Dye Mass Overflowing Weir Station	Median Retention Time for This Test (min)
A	0.718	31.7
B	0.794	35.1
C	0.802	36.9
D	0.808	38.1

* See Table 5 for explanation of station locations.

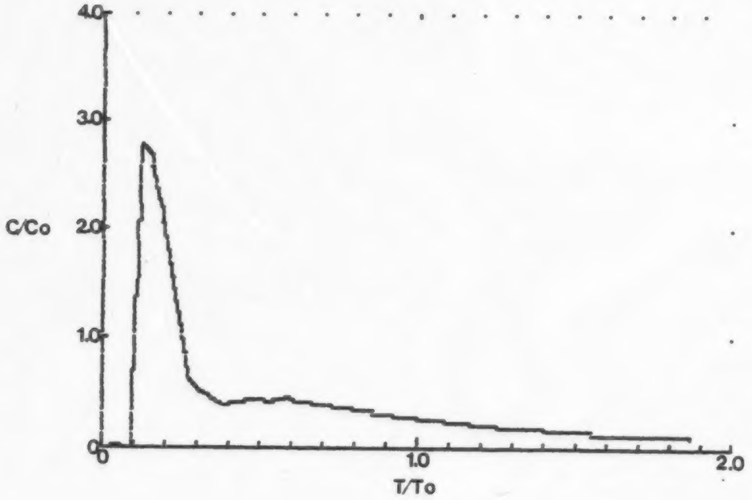


Figure 53. Results of the Multi-Point Dispersion Test for the Holly Hill south clarifier, weir station A, 29 August 1979.

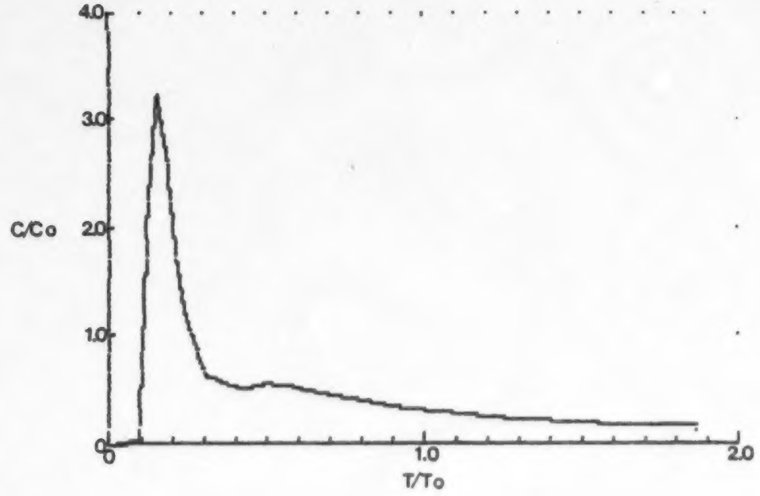


Figure 54. Results of the Multi-Point Dispersion Test for the Holly Hill south clarifier, weir station B, 29 August 1979.

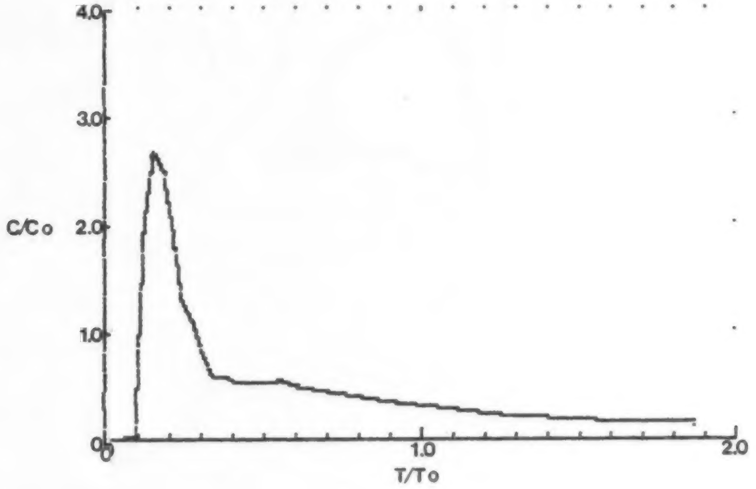


Figure 55. Results of the Multi-Point Dispersion Test for the Holly Hill north clarifier, weir station C, 29 August 1979.

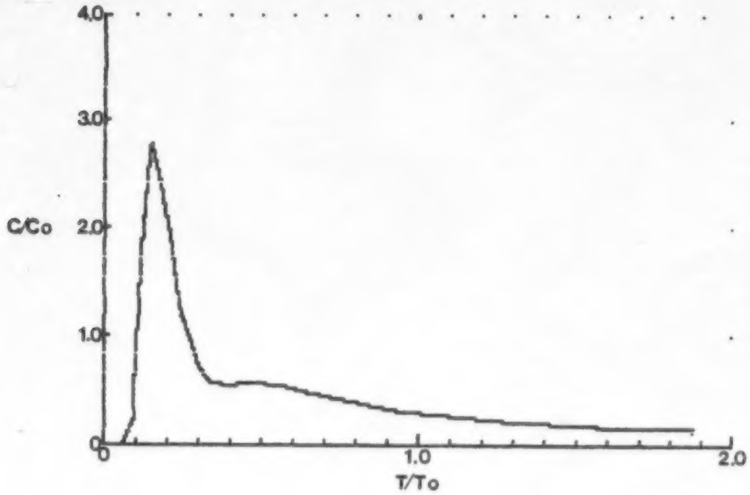


Figure 56. Results of the Multi-Point Dispersion Test for the Holly Hill north clarifier, weir station D, 29 August 1979.

Unsteady Flows at Holly Hill--

The influence of lift stations on plant throughflows was discussed earlier and illustrated in Figure 30. As a direct result of calculations on the incomplete comparative performance data at Holly Hill, a preliminary mathematical model was derived[5] to aid the investigator in understanding the flow-related physical phenomena which might affect clarifier performance. Both the unmodified north clarifier and the newly baffled south clarifier produced a measurably better effluent quality when flows were smoothed by the stop gate upstream of the aeration basins. Further, use of the stop gate appeared to widen the difference between the performance of the newly baffled and unmodified units.

On 17 September 1979, a day of high plant flow due to infiltration, but no rainfall, detailed measurements of the south clarifier's discharge were made with and without the stop gate in place. The flow data, presented in Figures 57 and 58, may be significant because the mathematical model, which will be presented in Section 7, predicts that the amplitude and frequency of flow rate changes will both affect the continued suspension and transport of solids within a clarifier. Inspection of Figures 57 and 58 will show that the amplitude and frequency of flow variation are both decreased when the stop gate is in place.

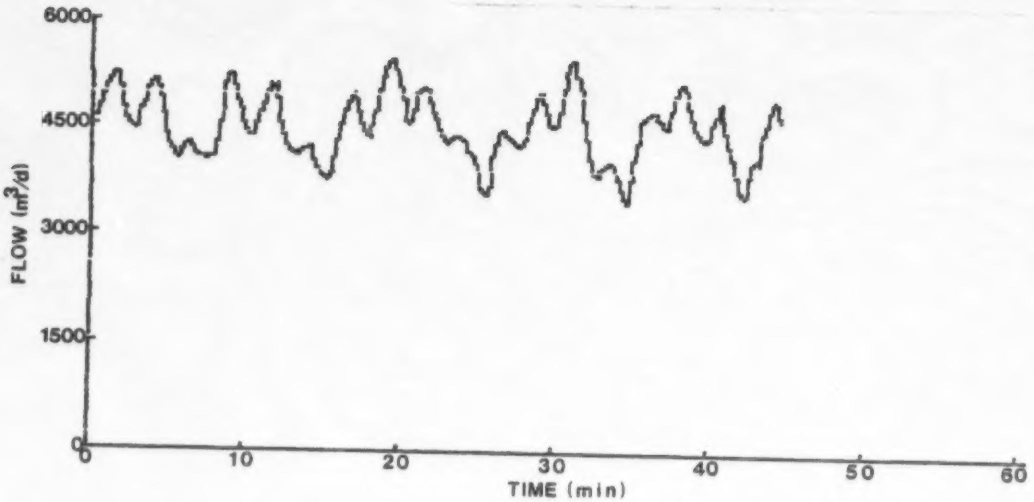


Figure 57. Discharge from the Holly Hill south clarifier without the upstream stop gate, 17 September 1979. Measurement interval was 12 sec.

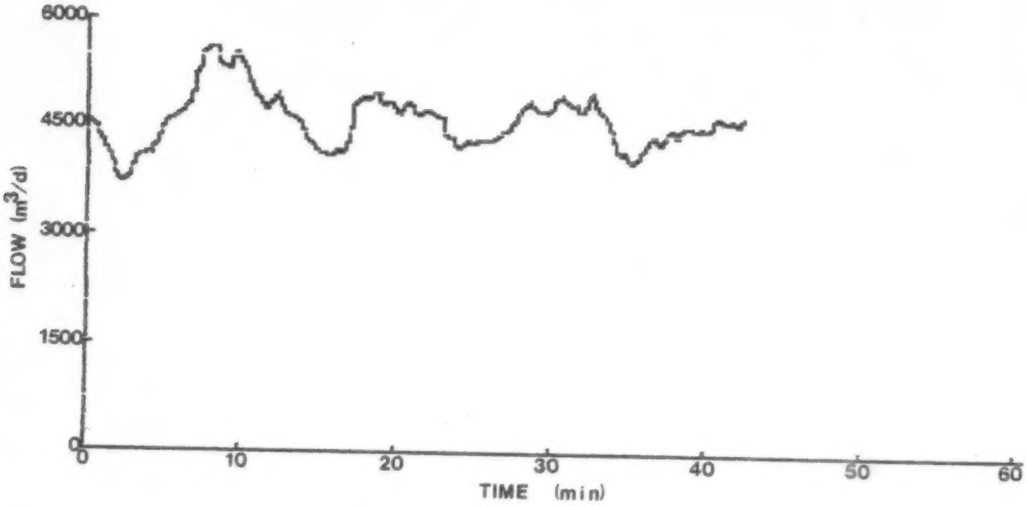


Figure 58. Discharge from the Holly Hill south clarifier with the upstream stop gate in place, 17 September 1979. Measurement interval was 12 sec.

Performance Evaluation--

Two different modifications were evaluated at Holly Hill:

1. Baffles, inlet channel flow equalizing blocks and inlet separators.

2. The use of flow-smoothing storage, upstream of the aeration basins.

A complete listing of the comparative performance data are found in Appendix B. Plots of the data are found in Appendix C. The investigator has summarized the effluent total suspended solids comparison in Table 7, which requires some explanation. For convenience in data reduction, four seperate periods were analyzed:

12 March - 31 May - This was the time during which the original reaction baffles were in place.

1 June - 31 July - The reaction baffles had received their final revision, a bottom plate, on 1 June.

1 August - 31 October - This period began normally, but the optical blanket finder was out of commission 15 August to 10 September. On 3 September, hurricane David initiated a period of abnormally high rainfall which continued through early October.

1 November - 3 December - Final data set.

The only conditions required for data to be included in the averages were that the blanket was less than 2 ft (0.6 m) thick, that the values of TSS for both clarifiers were known and that the open or closed state of the storage gate could be determined. The specific days when these conditions were met can be found by reference to the complete data listing in Appendix B.

Under the conditions stated above, average values of effluent TSS for the two clarifiers is presented in Table 7. During all periods, the south clarifier exhibited measurably better performance than the unmodified north unit. Similarly, both units appeared to perform better with the storage gate in use. The least difference, 7.6%, was noted during the third data period for the 27 days during which the storage gate was not in use. The greatest difference, 30.1%, was seen during the second data period with the storage gate in use.

TABLE 7. SUMMARY OF EFFLUENT TSS PERFORMANCE OF THE HOLLY HILL SECONDARY CLARIFIERS DURING THE STUDY PERIOD - 12 MARCH - 3 DECEMBER 1979

	Storage Gate Not Used				Storage Gate In Use			
Study Period	No. of Days in Record	North, or Control Clarifier TSS(mg/l)	South, or Test Clarifier TSS(mg/l)	Reduction in TSS(%)	No. of Days in Record	North, or Control Clarifier TSS(mg/l)	South, or Test Clarifier TSS(mg/l)	Reduction in TSS(%)
12 Mar-31 May	35	29.5	25.6	13.2	17	20.4	16.8	17.6
1 Jun-31 Jul	32	24.8	20.4	17.7	16	17.3	12.1	30.1
1 Aug-31 Oct	27	28.6	26.4	7.6	16	27.9	24.6	11.8
1 Nov-3 Dec	17	35.6	29.4	17.4	11	33.2	28.9	13.0
	111	28.9*	24.9*	13.8	60	23.9*	19.8*	17.2

* These numbers are true averages, weighted by the number of days in the record for each study period.

A separate calculation of interest is the performance of the two clarifiers at various flow rates. Table 8 lists effluent TSS as a function of overflow computed at intervals of 0.20 mgd (760 m^3/d) over the total flow range measured during the study. (With a total surface area for the two units of 2080 sq ft (193 m^2), this translates to a surface area overflow rate range of 455-1680 gpd/sq ft (18.5-68.2 $m^3/m^2 \cdot d$). The data for flow rates above 1.88 mgd (7120 m^3/d) were not included because of the limited number of data points available. Within the flow range of 0.95 to 1.68 mgd (3580 to 6340 m^3/d), the test clarifier produced an effluent with approximately 20% less TSS. Comparative measurements for the two clarifiers are presented in Figure 59.

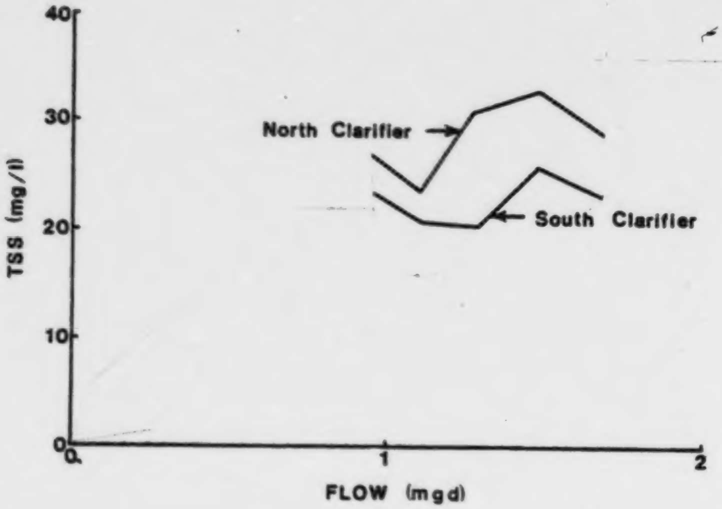


Figure 59. Effluent TSS versus flow for the two clarifiers at Holly Hill.

TABLE 8. HOLLY HILL CLARIFIER EFFLUENT TSS AS A FUNCTION OF FLOW RATE

Flow Range (mgd)	No. of Days in Average	Average Flow This Range (mgd)	Overflow Rate gpd/sq ft	Effluent TSS (mg/l) North Clarifier	Effluent TSS (mg/l) South Clarifier
.80 - .99	20	0.95	455	26.6	23.3
1.00 - 1.19	77	1.01	486	23.4	20.7
1.20 - 1.39	33	1.27	609	30.8	19.8
1.40 - 1.59	15	1.47	707	32.7	25.7
1.60 - 1.79	10	1.68	806	28.4	22.8

Morganton, North Carolina

Facility Description--

Hydraulic studies were completed and two modifications were evaluated at the City of Morganton's municipal wastewater treatment facility. This plant utilizes an oxygen activated sludge process to treat an influent with a significant industrial contribution, notably from textile and furniture manufacturing and poultry processing. A process schematic is presented in Figure 60.

The plant has two 80 ft (24.4 m) diameter center feed, peripheral overflow clarifiers as shown in Figure 61. Sidewater depth is 10 ft (3.0 m), with a very slight bottom slope. Design effluent rate of each unit is 4 mgd (15,000 m^3/d). The inlet feedwells have solid walls and are 16 ft (4.9 m) in diameter with a submerged depth of 5 ft (1.5 m). Sludge is removed by 8 riser pipes distributed along the scraper arms. A scum baffle is provided and scum is raked to a sump on each revolution of the sludge arms. The clarifiers have weirs at the tank periphery only. Originally, riser pipe rotation rate was 1 revolution per 33.7 min.

A venturi flowmeter provides measurement of the total underflow from both secondaries. A venturi type flowmeter also guages total plant influent rate, but the installed meter is intended for much greater flow rates and is inaccurate at present, relatively low influent rates.

Mixed liquor is fed to the two secondaries from a common splitter box. With both downstream gate valves fully open, imbalance was frequently observed. There was no effective method for achieving flow balance.

Prior to this study, Morganton had experienced performance problems that were thought to be related to their secondary clarifiers. Clarifier problems were believed to include: (1) clogging of sludge riser pipes by fibers, (2) a persistent "cake" of feathers, fiber and grease within the feedwells, and (3) an apparent hydraulic imbalance between secondaries, with no effective means for flow control.

Raw sewage reaches the plant via a single lift station with fixed-speed pumps. Recent practice has been to manually control pump operation, utilizing storage available in the wet well and collection system, so that plant flow is a nearly constant high rate from late morning until midnight, and a similarly constant, but low, flow rate during early morning hours.

Since there was no instrumentation provided for measuring the hydraulic loads of the two secondary clarifiers individually, sharp-crested rectangular weirs were installed at the points of

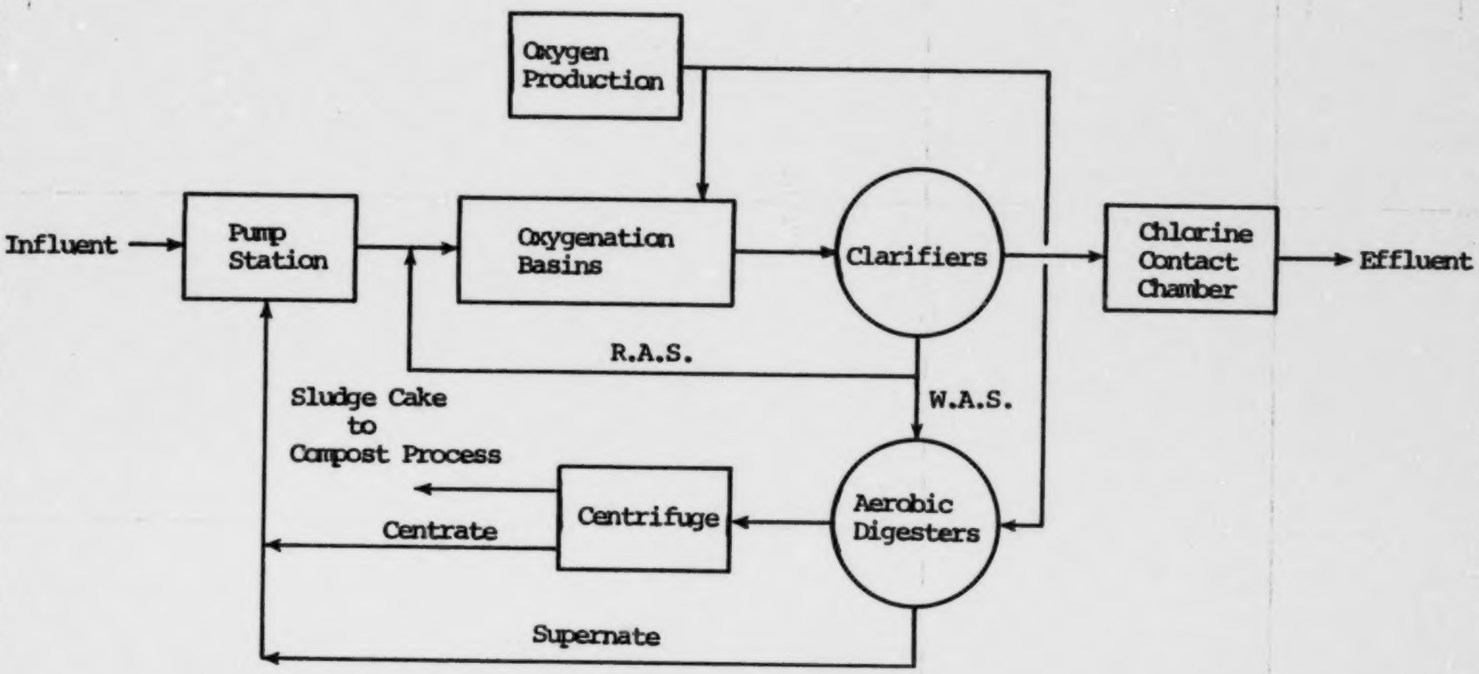
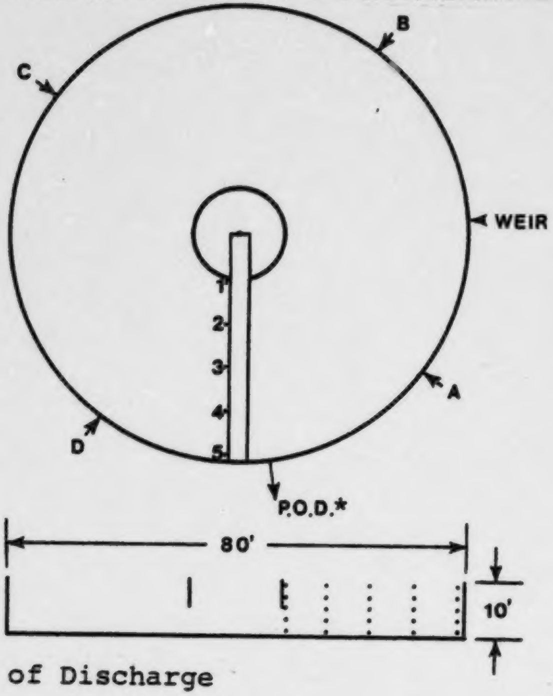

Oxygen Production
Influent
Pump Station
Oxygenation Basins
Clarifiers
Chlorine Contact Chamber
Effluent
R.A.S.
W.A.S.
Sludge Cake to Compost Process
Centrifuge
Aerobic Digesters
Centrate
Supernate

Figure 60. Process schematic for the Morganton, NC wastewater treatment facility.



*Point of Discharge

Figure 61. Plan and elevation of the Morganton, NC secondary clarifier #1.

discharge of the effluent launders of each clarifier. Two recording level guages were installed behind the measurement weirs of #1, the test clarifier. The measurement weirs of the control clarifier #2, were fitted with metal staff guages.

Dye dilution calibration of the weirs was attempted, but the results were unsatisfactory because of insufficient dye/effluent mixing. Standard weir formulas were therefore used.

Initial Hydraulic Test Results--

A Multi-Point Dispersion Test was conducted on 29 April 1979 by diverting the entire plant flow to clarifier #1 to approximate design hydraulic load conditions. Effluent rate during the test was 2.37 mgd (8960 m^3/d). This corresponds to a surface area overflow rate of 471 gpd/sq ft (19.19 $m^3/m^2 \cdot d$). Design effluent rate is 4 mgd (15,000 m^3/d). Although underflow rate was maintained at 1.75-1.80 mgd (6620-6810 m^3/d) during the dispersion test, the blanket rose to an unusually high 4.0-4.5 ft (1.2-1.4 m) thickness. The test was run on Sunday, with the intent of avoiding interference with visual observations of surface dye distribution caused by relatively high textile dye concentrations normally seen at this plant. Although color was only slight during the morning, the appearance could be most accurately described as approximately that of grape Kool-Aid by noon. The textile dyes are only moderately fluorescent at Rhodamine WT wave lengths; interference with measured Rhodamine concentrations was assumed to be a constant and correctable 25 ppb.

After an instantaneous release of 150 ml of dye at the reactor discharge, individual samples were retrieved from weir stations A, B, and C at 5 min intervals for two hours and at 30 min intervals for the next 1.5 hours. A continuous record was made at station D, using the fluorometer's flow-cell, but the station D data were not reduced for presentation in this report because of problems in interpreting the different scale factors for the flow cell and cuvette attachments in the presence of high background fluorescence.

Table 9 includes the pertinent information used for calculation of dispersion characteristics. Figures 62 through 64 are the non-dimensional dispersion plots. Although it is tempting to read various interpretations into these plots, the shape of each curve is now thought to be dependent upon several factors, including inlet port location with respect to the sampling point, riser pipe mechanism location, random turbulent eddies in the tank and, perhaps, relative weir elevations.

TABLE 9. PHYSICAL DATA PERTINENT TO THE DISPERSION TEST ON MORGANTON SECONDARY CLARIFIER #1, 29 APRIL 1979

Background fluorescence = 25 ppb
Tank volume = 373,000 gal
Average effluent rate during test = 2.37 mgd
Average underflow rate during test = 1.78 mgd
Retention time based on influent rate, T_O = 129.8 min
150 ml of dye were used in test clarifier only
Flash mix fluorescence, C_O = 106.2 ppb

Weir Station	Relative Dye Mass Overflowing Weir Station	Median Retention Time for This Test (min)
A	0.506	104.3
B	0.661	95.0
C	0.747	92.8
D	Not determined	

Initial Flow Pattern/Solids Distributions Tests were conducted on clarifier #1 on 30 April 1979, under normal dry weather weekday flow conditions, with both secondary clarifiers in operation. Dye injection was begun approximately two hours after the daily high-flow (two pump) condition was established.

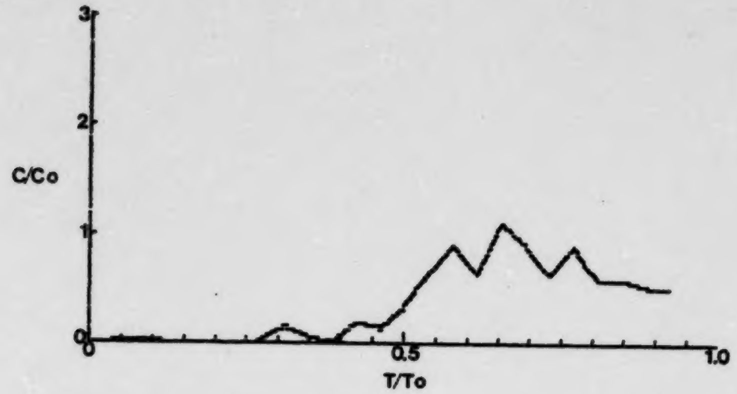


Figure 62. Results of the Multi-Point Dispersion Test for Morganton secondary clarifier #1, weir station A, 29 April 1979.

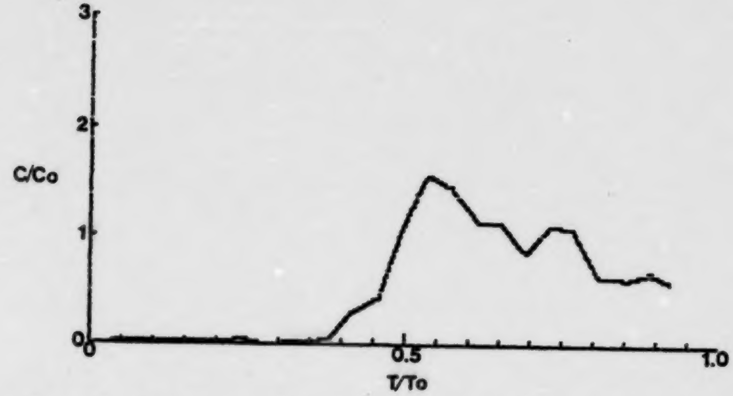


Figure 63. Results of the Multi-Point Dispersion Test for Morganton secondary clarifier #1, weir station B, 29 April 1979.

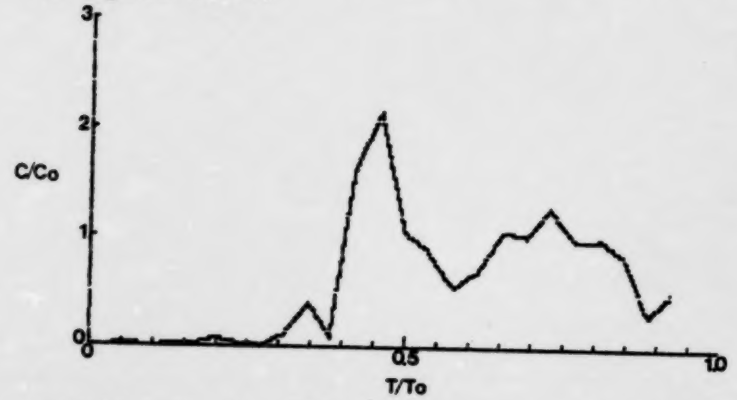


Figure 64. Results of the Multi-Point Dispersion Test for Morganton secondary clarifier #1, weir station C, 29 April 1979.

Total plant flow was measured as 4.55 mgd (17,200 m^3/d). This is equivalent to a surface area overflow rate of 452.4 gpd/sq ft (18.4 $m^3/m^2 \cdot d$). Total underflow was 1.54 mgd (5830 m^3/d). Flow and underflow was assumed as 50% of these values for each clarifier.

Dye injection, at a rate of 2.5 ml/min, was started as the scum skimmer arm passed peripheral station D. Three flow pattern sampling runs, of 4 min duration each, were begun after the skimmer arm passed peripheral stations B and D respectively, intervals of approximately 17 min. The results of the flow pattern runs are presented in Figures 65 through 67.

The distribution of solids in the radial section is shown in Figure 68. The flow pattern study clearly shows the rapid progress of a flow layer toward the weirs which, in Figure 65 is less than 1 ft (0.3 m) thick near the periphery of the tank. A sharp rebound of the fluid is also apparent in Figure 65.

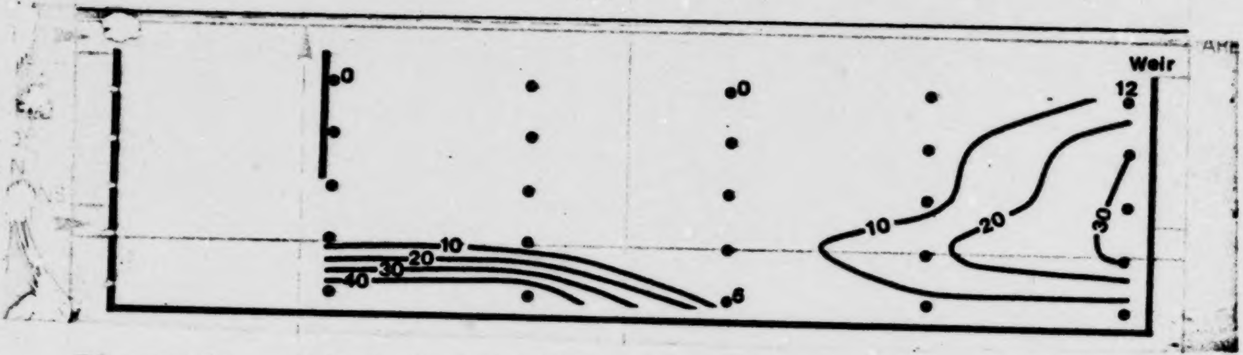


Figure 65. Radial distribution of the dye concentrations in Morganton clarifier #1, 19 min after the start of continuous dye injection, 30 April 1979.

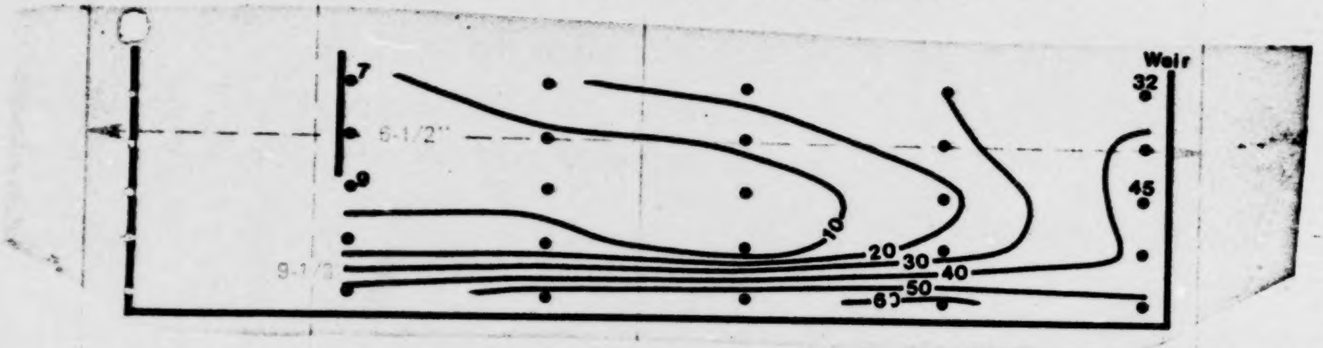


Figure 66. Radial distribution of the dye concentrations in Morganton clarifier #1, 36 min after the start of continuous dye injection, 30 April 1979.

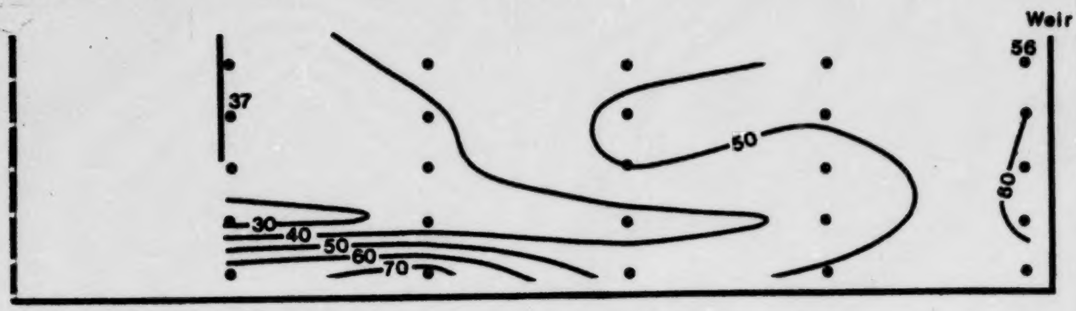


Figure 67. Radial distribution of the dye concentrations in Morganton clarifier #1, 52 min after the start of continuous dye injection, 30 April 1979.

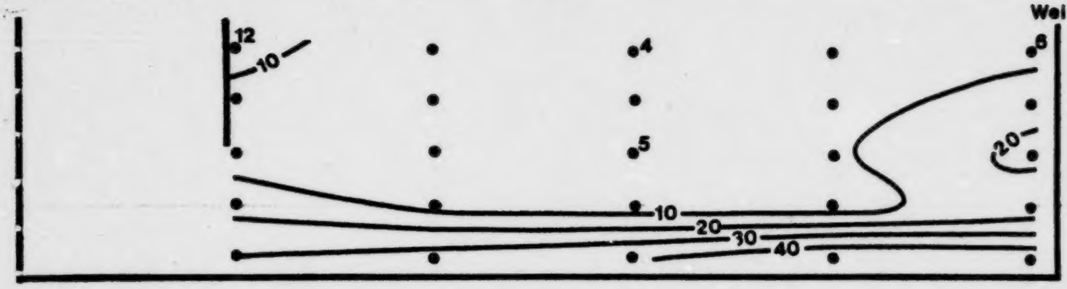


Figure 68. Radial distribution of the square root of total suspended solids in Morganton clarifier #1, 30 April 1979.

The effect of this flow on the solids distribution is shown in Figure 68; there is a greater concentration of solids on the bottom near the periphery and lighter solids are being transported upward toward the overflow weir.

It is useful to note the available auxiliary process data taken during the flow pattern study. This information is presented in Table 10.

A Weir-Wall Solids Test was also conducted on 30 April 1979, including a time-series of 19 samples taken at two minute intervals at each of 5 depths at bridge station 5. The 95 samples were analyzed for total suspended solids and concentrations were plotted against time to detect possible solids variability due to effects of riser pipe mechanism rotation. The test results are presented in Figures 69 through 73. A great deal of variability in solids concentration was noted at all sample depths, but the greatest concern, because of potential effects on effluent quality, was the variability nearest the overflow weir, Figure 69.

TABLE 10. PROCESS DATA ON THE TEST CLARIFIER, MORGANTON, NC, 1300, 30 APRIL 1979

MLTSS	3600 mg/l
Eff. TSS (grab)	52 mg/l

Settleometer test

Time (min)	Settled Sludge Volume
0	1000
5	300
10	225
15	195
20	185
30	170 SVI = 47

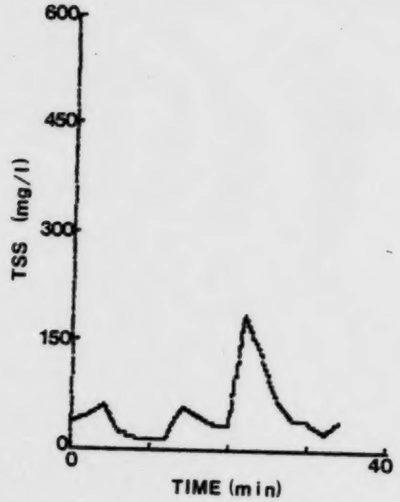


Figure 69. Weir-Wall Solids Concentration versus Time at a depth of 1 ft (0.3 m), Morganton secondary clarifier #1, 30 April 1979. Average value is 49.2 mg/l.

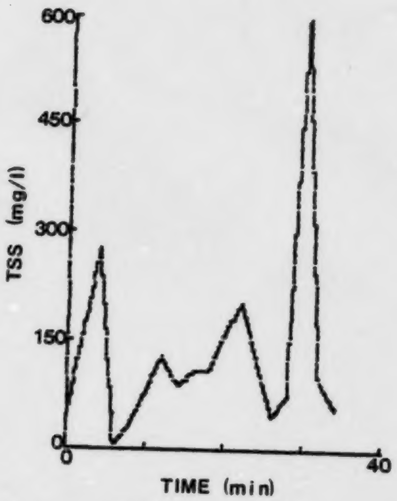


Figure 70. Weir-Wall Solids Concentration versus Time at a depth of 3 ft (0.9 m), Morganton secondary clarifier #1, 30 April 1979. Average value is 130.9 mg/l.

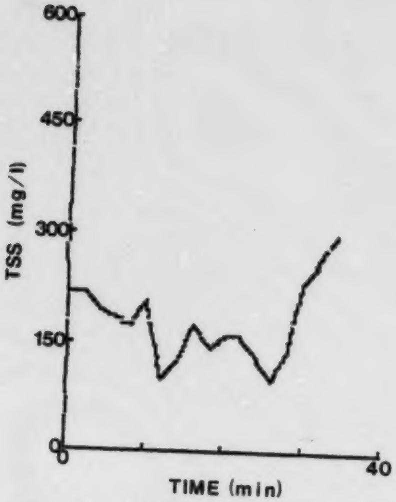


Figure 71. Weir-Wall Solids Concentration versus Time at a depth of 5 ft (1.5 m), Morganton secondary clarifier #1, 30 April 1979. Average value is 176.8 mg/l.

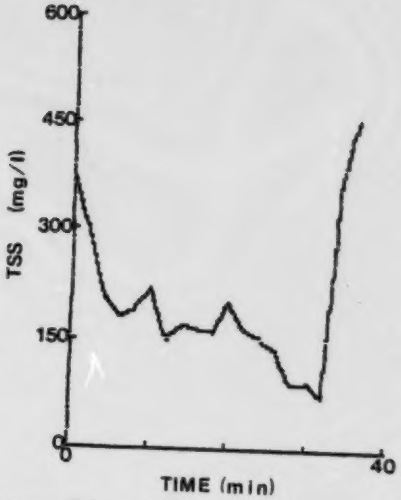


Figure 72. Weir-Wall Solids Concentration versus Time at a depth of 7 ft (2.1 m), Morganton secondary clarifier #1, 30 April 1979. Average value is 201.3 mg/l.

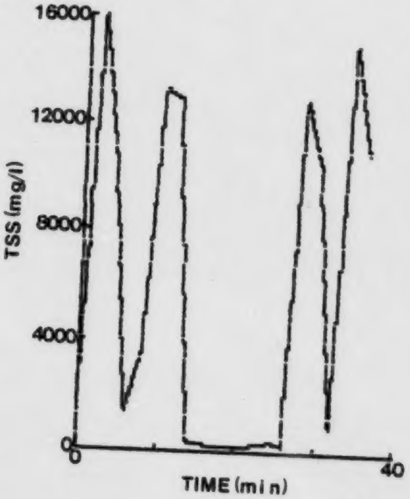


Figure 73. Weir-Wall Solids Concentration versus Time at a depth of 9 ft (2.7 m), Morganton secondary clarifier #1, 30 April 1979. Average value is 579.6 mg/l.

The Weir-Wall Solids Test results, although not precisely correlated with sludge header rotation, were suggestive of an effect. As at Albuquerque, the investigator expected to see a "solids wave" effect. From the Stamford data, to be presented later in this section, the "solids wave" is now thought to be an inlet jet effect. As at Albuquerque, the investigator failed to note the positions of the inlet ports with respect to the test position at Morganton.

Conclusions From Initial Hydraulic Test Results--

Following field work-up of the data already presented, a conference was called by the investigator with City operating and administrative personnel and the City's consulting engineers, O"Brien and Gere. The concensus of the meeting was:

1. Undesirably high velocity outward currents existed along the bottom of the tank, resulting in upflow of excessive solids on the weir wall. A large proportion of the tank's volume was not effectively utilized for settling.

2. The sludge riser pipe structure perturbed solids as it swept the bottom. The near-surface effects of this motion hindered settling and probably degraded effluent quality. As was discussed, this conclusion was probably wrong.

Because of the relative ease of accomplishment, it was decided to first evaluate the potential benefit of slowing the rotational speed of the riser pipe mechanism. A speed reduction from 1/33.7 min to 1/60.2 min (56%) was accomplished by a change in sprocket ratio at the center-of-tank drive train.

Result of Slowing the Riser Pipe Mechanism--

Hydraulic Test Results--A Weir-Wall Solids Test was conducted on 12 November 1979. The test included 25 samples at approximately three min intervals at each of two depths, 1 and 3 ft (0.3 and 0.9 m). Total test duration was 73 min. The test results are presented in Figures 74 and 75. Figure 74, the plot of data at 1 ft (0.3 m) seems to be generally smoother than its pre-modification companion Figure 69, but the average value of total suspended solids was higher, 63.6 mg/l versus 49.2 mg/l, and the last data point was a high value, 180 mg/l. Figure 75, the plot of data at 3 ft (0.9 m) was also less variable than Figure 70 and the average of all data was lower, 77.8 mg/l versus the pre-modification average of 131 mg/l. The significance of those values is uncertain; differences in process variables were not recorded.

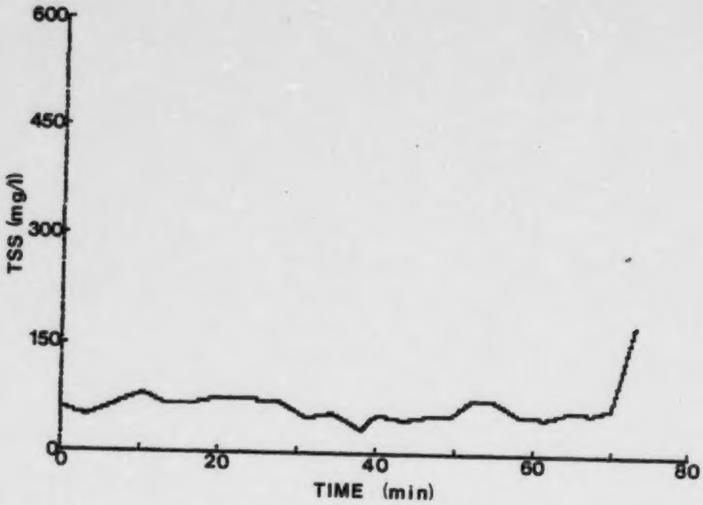


Figure 74. Weir-Wall Solids Concentration versus Time at a depth of 1 ft (0.3 m), Morganton secondary clarifier #1, 12 November 1979. Average value is 63.6 mg/l.

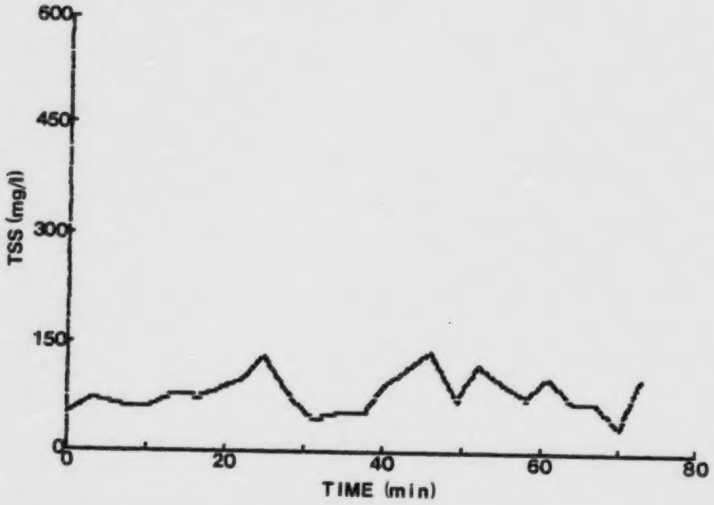


Figure 75. Weir-Wall Solids Concentration versus Time at a depth of 3 ft (0.9 m), Morganton secondary clarifier #1, 12 November 1979. Average value is 77.8 mg/l.

Performance Evaluation--Modified clarifier #1 was compared with unmodified #2 for 106 days with the aid of the following daily parameters:

- Total plant flow for 24 hours
- Total secondary underflow rate
- Percent flow split between the two clarifiers during the high-flow hours
- Effluent TSS composite from the test clarifier during high-flow hours
- Effluent TSS composite from the control clarifier during high-flow hours
- MLTSS
- SVI
- Blanket thickness at mid-radius in the test clarifier
- Blanket thickness at mid-radius in the control clarifier
- Effluent COD from the test clarifier
- Effluent COD from the control clarifier

A complete listing of these data is given in Appendix D. With an average plant flow rate of 4.01 mgd (15,170 m^3/d), approximately half the design hydraulic loading, the modified clarifier discharged an average of 29.0 mg/l total suspended solids during peak flow hours while its "normal speed" neighbor discharged an average of 32.4 mg/l. The apparent improvement in performance was 10.4%. Hydraulic loads, blankets and COD's were essentially equal. Underflow was 2.93 mgd (11,100 m^3/d), 73% of overflow. Average SVI was 50. It is interesting to note, however, that although the investigator's conclusion regarding cause may not be correct, the effect of slowing the riser pipe mechanism was apparently beneficial.

Description of the Second Modification: The Ring Baffle/ Flocculation Chamber--
The initial flow pattern test defined a thin, high velocity flow across the bottom toward the tank's periphery. The current appeared to rebound sharply from the outer wall and there was a relatively high concentration of solids migrating upward toward the weir. The preferred, but more complex solution to this problem was to create a baffle structure at mid-radius, extending from mid-depth to as near the floor as practical. This structure is illustrated in Figure 76. The baffle and Styrofoam floatation blocks are suspended from steel structural members which, in turn, are attached to, and rotate with the feedwell and riser pipe mechanism. Riser pipes penetrate the baffle at two places.

In operation, it was expected that the ring baffle would entrap most of the solids; flow from the eight riser pipes was adjusted to return a greater mass of solids from within the ring. Additionally, it has been suggested that the ring baffle may act

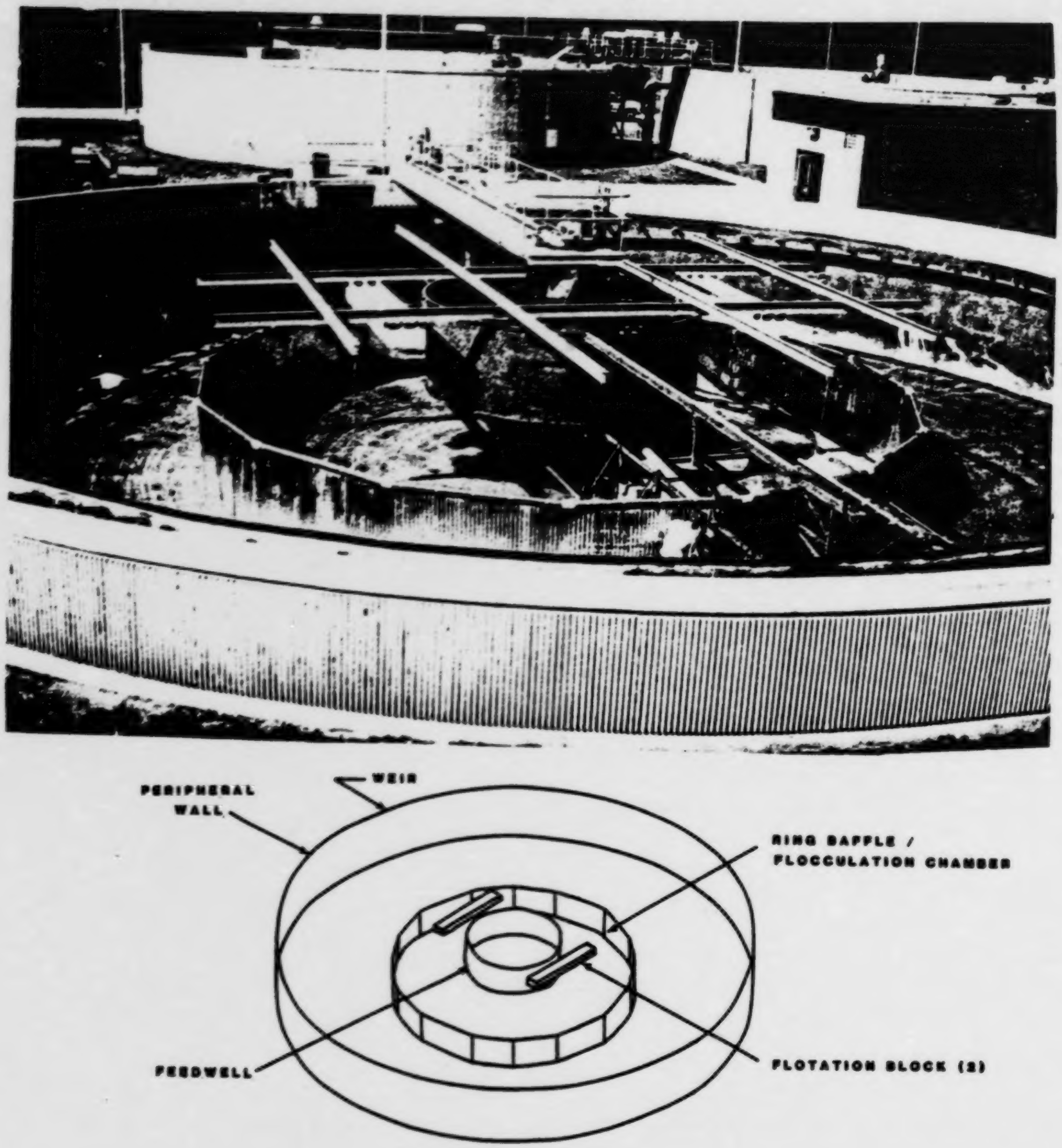

PERIPHERAL WALL
WEIR
RING BAFFLE / FLOCCULATION CHAMBER
FEEDWELL
FLOTATION BLOCK (2)

Figure 76. Ring Baffle/Flocculation Chamber installed in the Morganton, N.C. secondary clarifier #1. All structural elements shown in the center of the tank rotate with the riser pipe mechanism.

as a flocculation chamber. Thus, the modification is now referred to as a ring baffle/flocculation chamber.

To increase the validity of tests to evaluate the new baffle, the riser pipe mechanism in #2 clarifier was slowed to match the speed of #1's rotation. Thus, both clarifiers were again "identical" except for the new baffle structure in #1.

Hydraulic test results after the second modification--The only hydraulic test made to evaluate the Morganton baffle was a Flow Pattern/Solids Distribution Test. The results are presented in Figures 77 through 80. It should be noted that it is improper to contour across a physical discontinuity such as is formed by the baffle. Thus, dashed lines are inserted in these figures as the investigator's estimate of probable dye and solids distributions.

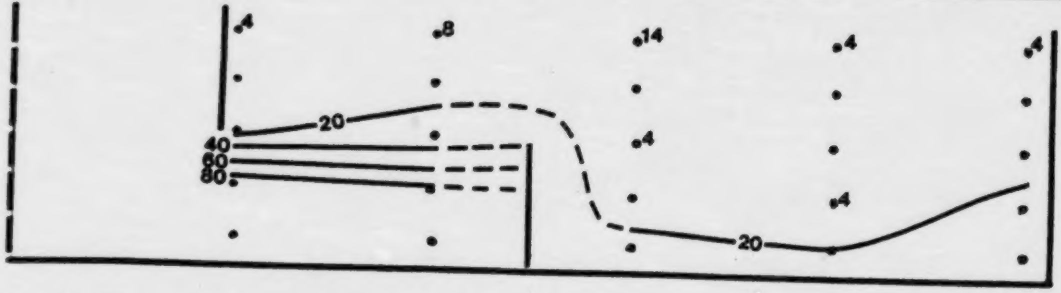


Figure 77. Radial distribution of the dye concentrations in Morganton clarifier #1, 19 min after the start of continuous dye injection, 16 April 1980.

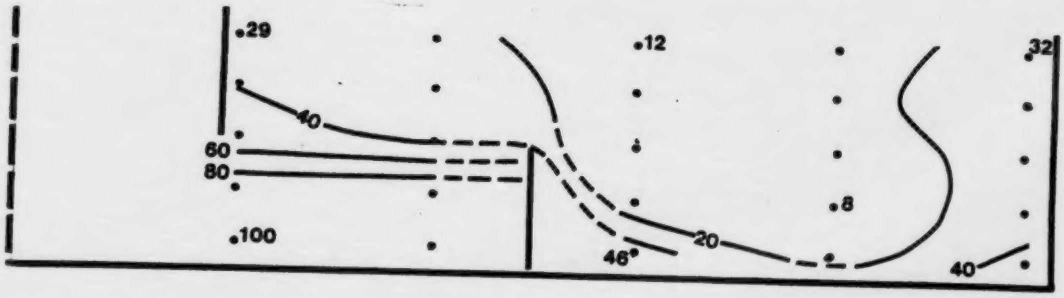


Figure 78. Radial distribution of the dye concentrations in Morganton clarifier #1, 38 min after the start of continuous dye injection, 16 April 1980.

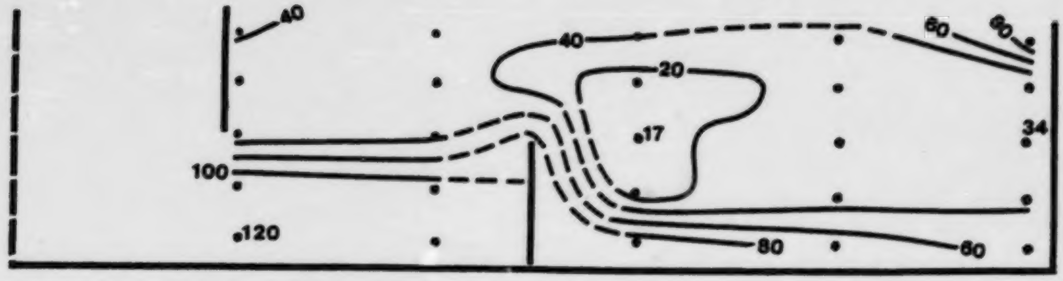


Figure 79. Radial distribution of the dye concentrations in Morganton clarifier #1, 57 min after the start of continuous dye injection, 16 April 1980.

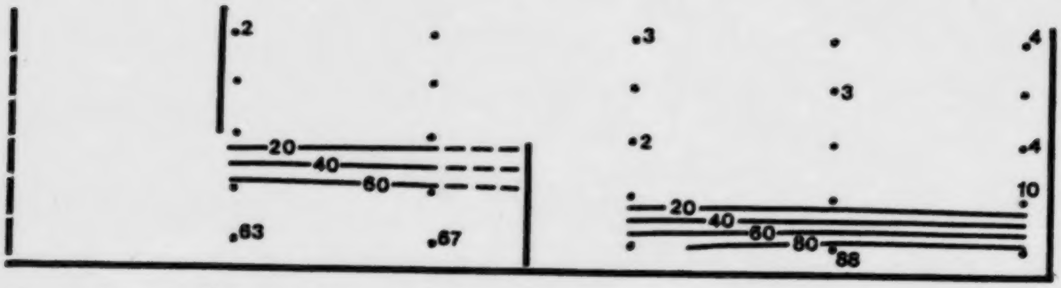


Figure 80. Radial distribution of the square-root of total suspended solids in Morganton clarifier #1, 16 April 1980.

Figures 77 through 80 suggest that a radical change has occurred in the flow regimes. A significant result is the relatively low solids concentration inside the ring, Figure 80: approximately the mixed liquor concentration. Higher, but unperturbed concentrations are seen outside the ring and there is little solids upflow on the peripheral wall.

Performance evaluation after the second modification--During the period 15 May to 4 September 1980, there were 80 days of usable comparative performance data including the following parameters:

- Overflow rate of each clarifier during peak flow hours
- Effluent TSS composite from #1 clarifier during peak flow hours
- Effluent TSS composite from #2 clarifier during peak flow hours
- MLTSS
- SVI
- Blanket thickness inside the baffle ring, #1 clarifier
- Blanket thickness outside the baffle ring, #1 clarifier
- Blanket thickness at mid-radius, #2 clarifier

A complete data listing for the 80 days is given in Appendix E. These data are segregated by two conditions: (1) 60 days of "normal" operating conditions and (2) 20 days of "bulking sludge" conditions.

It can be calculated that during the 60 day "normal" period, effluent TSS from #1 averaged 17.6 mg/l, while #2's effluent averaged 28.2 mg/l. This represents a decrease in TSS of 37.5% in the newly baffled unit. Under the 20 day "bulking sludge" condition, TSS averages were 52.3 mg/l for #1 and 89.1 mg/l for #2, a 41.3% improvement.

Follow-up observation--As of 10 June 1981, the prototype ring baffle was still in use at Morganton. Current practice is to utilize the baffled clarifier for approximately 60% of the total plant flow. By this expedient, the operator is able to consistently maintain effluent TSS within the permitted value.

Material cost for the riser pipe mechanism speed change was less than $100 per clarifier. Material cost for the ring baffle in #1 clarifier was approximately $3000. The modifications were accomplished by the plant operating staff.

Oakland, California East Bay Municipal Utility District (EBMUD)-Main Plant

Facility Description--

For this project, final clarifier number 11 at the EBMUD main plant was used to evaluate the hydraulic characteristics of a large diameter peripheral-feed, peripheral overflow circular clarifier. Extensive initial hydraulic tests at three overflow rates and two sludge blanket heights indicated that the hydraulic characteristics of these units could not be substantially improved with minor modifications within the scope of this project.

The EBMUD plant is an oxygen activated sludge facility. A process schematic is presented in Figure 81. The main plant has twelve, 140 ft (42.7 m) peripheral feed, peripheral overflow (PFPO) secondaries as shown in Figure 82. Sidewater depth is 14 ft (4.3 m). Bottom slope is very slight. Design effluent rate for each unit is 10 mgd (38,000 m^3/d).

Mixed liquor feed is automatically controlled at any set rate to each clarifier by means of a feedback loop between the electromagnetic flowmeter at the point of discharge of each unit and a butterfly valve adjacent to the common mixed liquor channel. Sludge is removed via a single tube suction header which rotates at one revolution per 35.5 min.

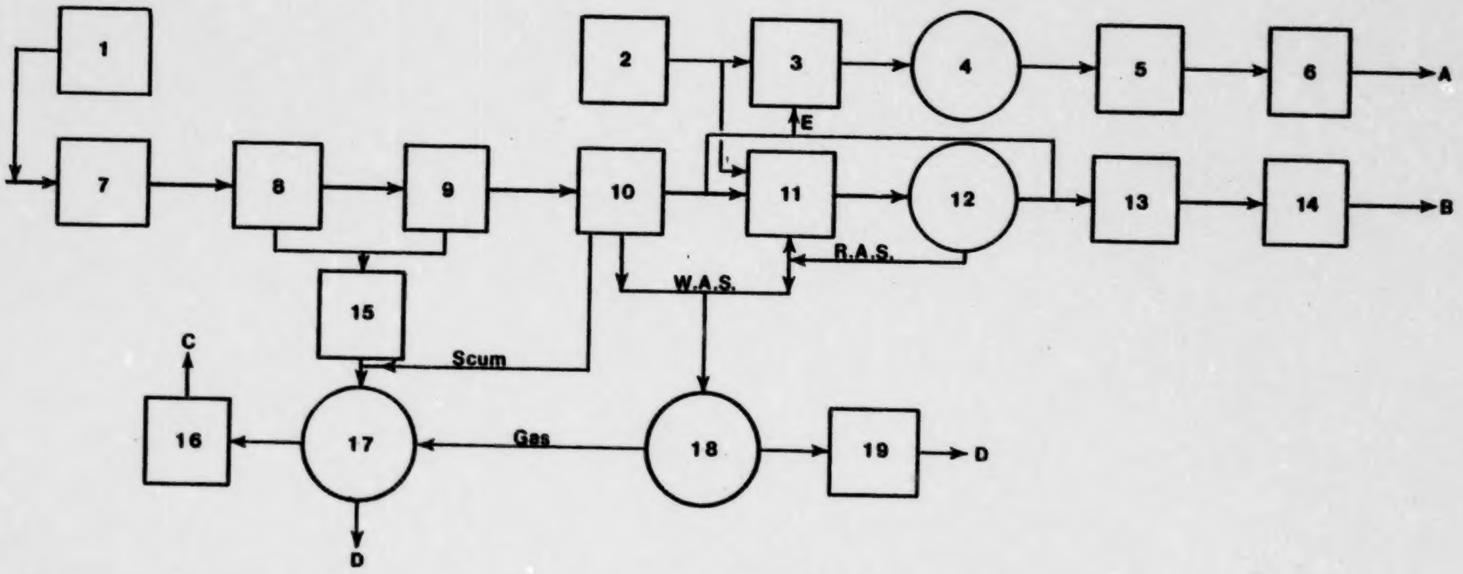
Flow to the peripheral inlet channel splits, just downstream of the servo controlled butterfly valve, to flow bidirectionally around the tank periphery. Mixed liquor is introduced to the main part of the clarifier from the peripheral inlet channel, downward, through multiple, individually baffled inlet ports. Scum removal is provided.

Underflow rate from each clarifier is individually metered and recorded, but flow control from the separate units is dificult.

Hydraulic Test Results--

Multi-Point Dispersion Tests and Flow Pattern/Solids Distribution Tests were completed with clarifier #11 operating at 65%, 100%, and 150% of the design surface overflow rates. Additionally, a Flow Pattern/Solids Distribution Test was completed at the design surface overflow rate but under a high sludge blanket condition. The results will be given in order of ascending overflow rate.

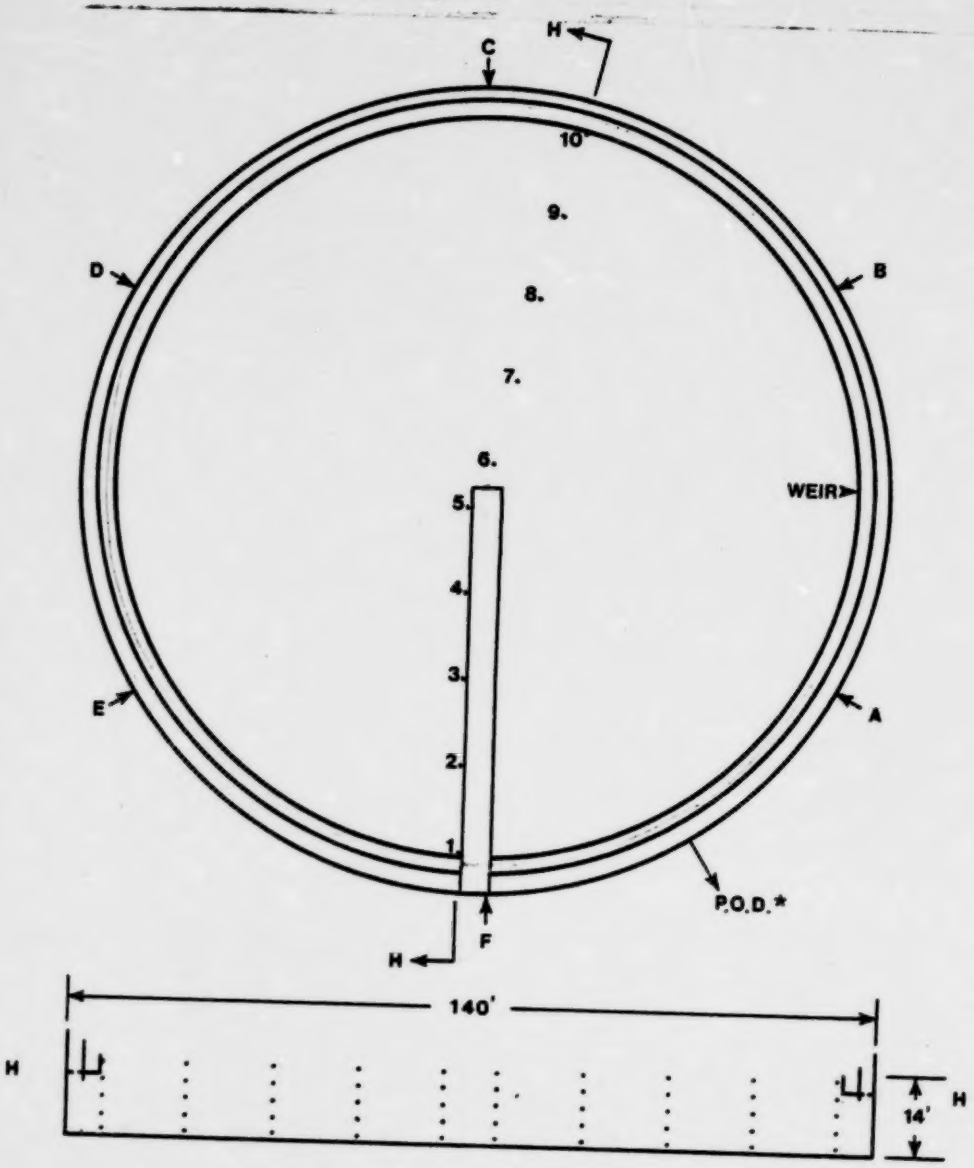
The flow pattern contour charts presented in this section are somewhat different in appearance from those presented earlier. Contours were computer generated; additional line interpolations and concentration values were added, by hand, for clarity.



1. Pre Chlorination
2. Oxygen Production Plant
3. Nitrification (Process Water)
4. Clarification (Process Water)
5. Chemical Sedimentation (Process Water)
6. Filtration
7. Bar Screen
8. Grit Chamber
9. Aerated Grit Chamber
10. Primary Clarifiers
11. Oxyenation Tanks (Aeration Basins)
12. Secondary Clarifiers
13. Post Chlorination
14. De-chlorination (SO_2)
15. Grit Dewater
16. Air Pollution Control
17. Grit and Scum Incinerator
18. Digester
19. Sludge Dewater

A. Effluent for Plant Use
B. Effluent to San Francisco Bay
C. Atmosphere
D. Truck Disposal
E. Process Water Influent

Figure 81. Process schematic for the East Bay Municipal Utility District (EBMUD) plant at Oakland, CA.


H
C
10'
9.
8.
7.
6.
5.
4.
3.
2.
1.
D
B
WEIR
E
A
P.O.D.*
F
H
140'
H
H
14'

*Point of Discharge

Figure 82. Plan and elevation of the East Bay Municipal Utility District's secondary clarifier #11.

Test results at 65% of design overflow rate--A Multi-Point Dispersion Test was conducted on 2 February 1979. During the test, effluent rate was controlled at 6.25 mgd (23,600 m^3/d). This corresponds to a surface area overflow rate of 406 gpd/sq ft (16.5 $m^3/m^2 \cdot d$). Underflow was maintained at 0.60 mgd (2270 m^3/d). The blanket thickness varied from 2-4 ft (0.6-1 m).

Physical data pertinent to the 63% Multi-Point Dispersion Test is summarized in Table 11. The six dispersion curves are shown as Figures 83 through 88.

TABLE 11. PHYSICAL DATA PERTINENT TO THE DISPERSION TEST ON EBMUD SECONDARY CLARIFIER #11 AT 65% OF DESIGN OVERFLOW RATE, 2 FEBRUARY 1979

Background fluorescence = 3.2 ppb
Tank volume = 1,610,000 gal
Effluent rate during test = 6.25 mgd
Underflow rate during test = 0.60 mgd
Retention time based on influent rate, T_O = 338.9 min
275 ml of dye was added to test clarifier only
Flash mix fluorescence, C_O = 45.1 ppb

Weir Station	Relative Dye Mass Overflowing Weir Station	Median Retention Time for This Test (min)
A	0.788	152.2
B	0.750	174.4
C	0.783	175.9
D	0.897	157.3
E	0.872	143.9
F	0.797	153.3

The dispersion plots are all similar in appearance, indicating a relatively rapid "first arrival" time, but exhibiting a sustained high concentration.

Pertinent auxiliary data for 2 February 1979 are as follows:

Solids

1010 -	MLTSS	3400 mg/l
	Effluent TSS (grab)	18 mg/l
	SVI	41
1540 -	MLTSS	3800 mg/l
	Effluent TSS (grab)	10 mg/l
	SVI	54

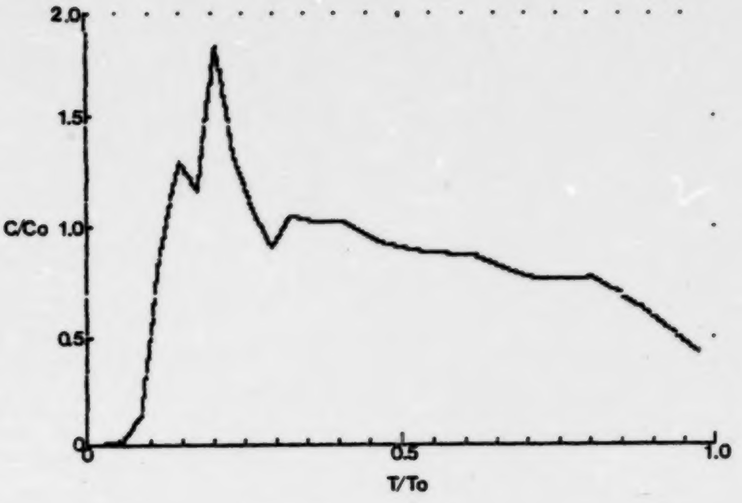


Figure 83. Results of the Multi-Point Dispersion Test for EBMUD secondary clarifier #11, weir station A, 2 February 1979.

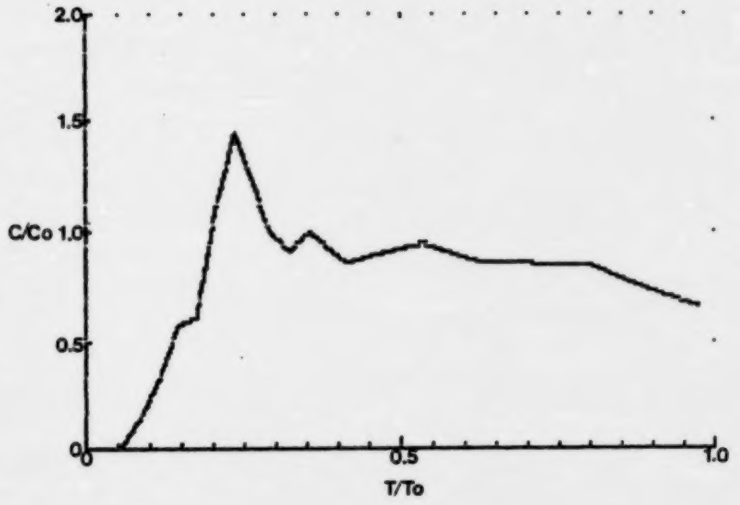


Figure 84. Results of the Multi-Point Dispersion Test for EBMUD secondary clarifier #11, weir station B, 2 February 1979.

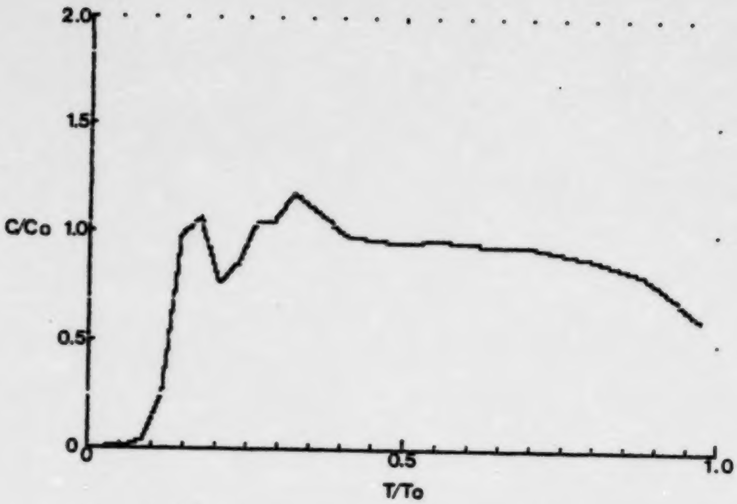


Figure 85. Results of the Multi-Point Dispersion Test for EBMUD secondary clarifier #11, weir station C, 2 February 1979.

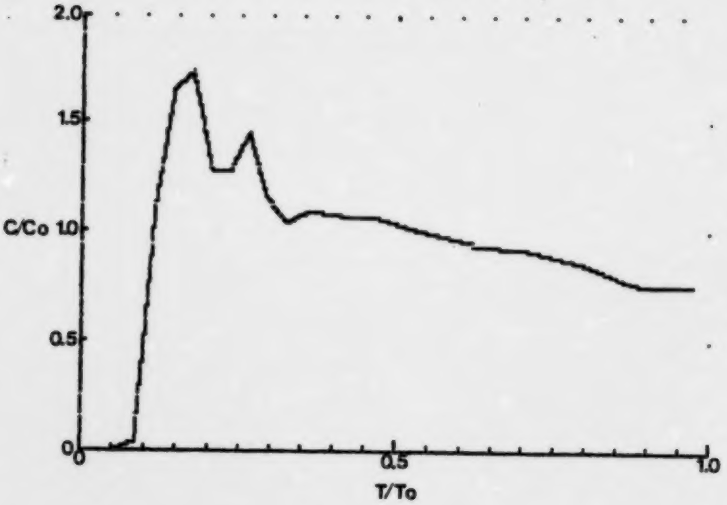


Figure 86. Results of the Multi-Point Dispersion Test for EBMUD secondary clarifier #11, weir station D, 2 February 1979.

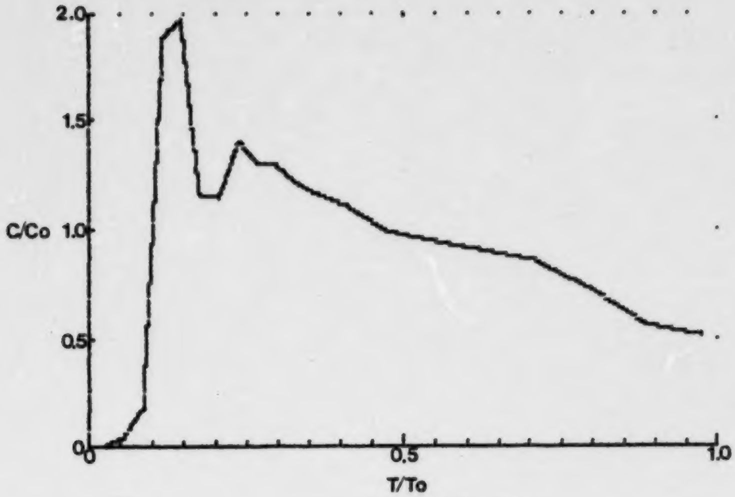


Figure 87. Results of the Multi-Point Dispersion Test for EBMUD secondary clarifier #11, weir station E, 2 February 1979.

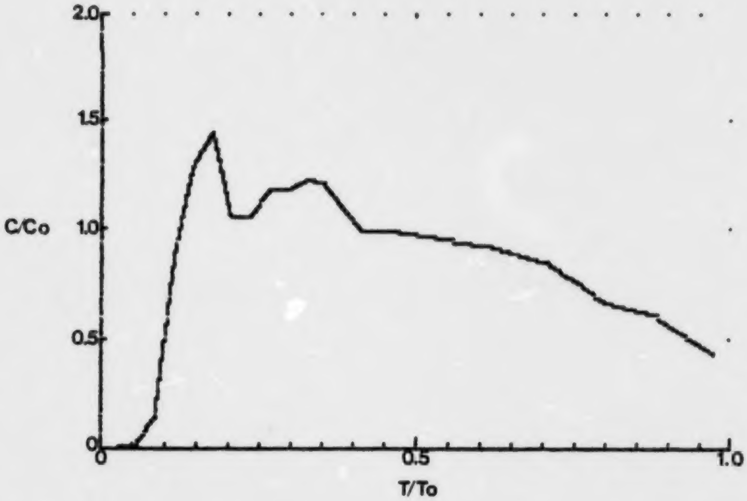


Figure 88. Results of the Multi-Point Dispersion Test for EBMUD secondary clarifier #11, weir station F, 2 February 1979.

During the Flow Pattern/Solids Distribution Test on 3 February 1979, rate was held nearly constant at 6.5 mgd (24,600 m^3/d). This corresponds to a surface area overflow rate of 422 gpd/sq ft (17.19 $m^3/m^2 \cdot d$). Underflow was too low for accurate measurement. The blanket was approximately 3 ft (0.9 m) thick. Dye injection, at a rate of 2.6 ml/min, followed by three sampling runs at bridge stations 1-5, resulted in the flow pattern time series, Figures 89 through 91 and the solids distribution plots, Figures 92 and 93.

In comparing these flow pattern data with similar series in this report from center feed circular clarifiers, it should be noted that the interval between flow patterns is approximately double that of the others. Thus, relatively speaking, the phenomena are being observed in "slow-motion".

The tracer progressed across the top of the sludge blanket in much the same pattern as in the center feed units. In this clarifier, however, there is no wall on the right-hand side of the illustrations. There is only a relatively small diameter support column in the center of the tank, represented as a vertical dashed line. Additionally, if flows are balanced from all peripheral inlet ports, flows should converge at this location.

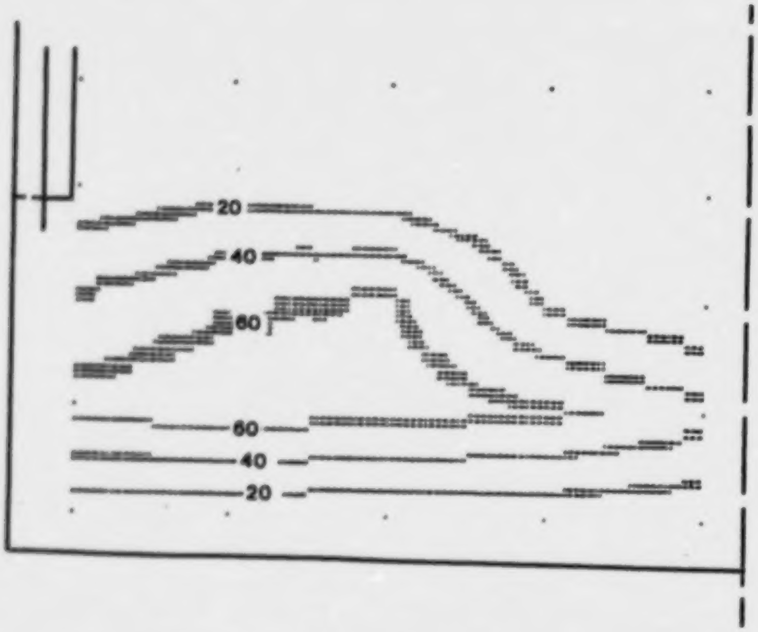


Figure 89. Radial distribution of the dye concentration in EBMUD secondary clarifier #11, 35 min after the start of continuous dye injection, 3 February 1979.

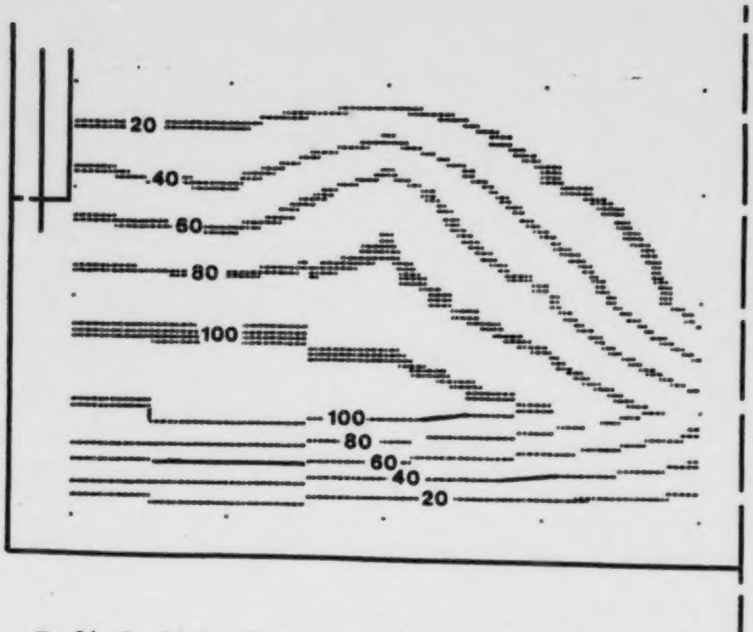


Figure 90. Radial distribution of the dye concentration in EBMUD secondary clarifier #11, 70 min after the start of continuous dye injection, 3 February 1979.

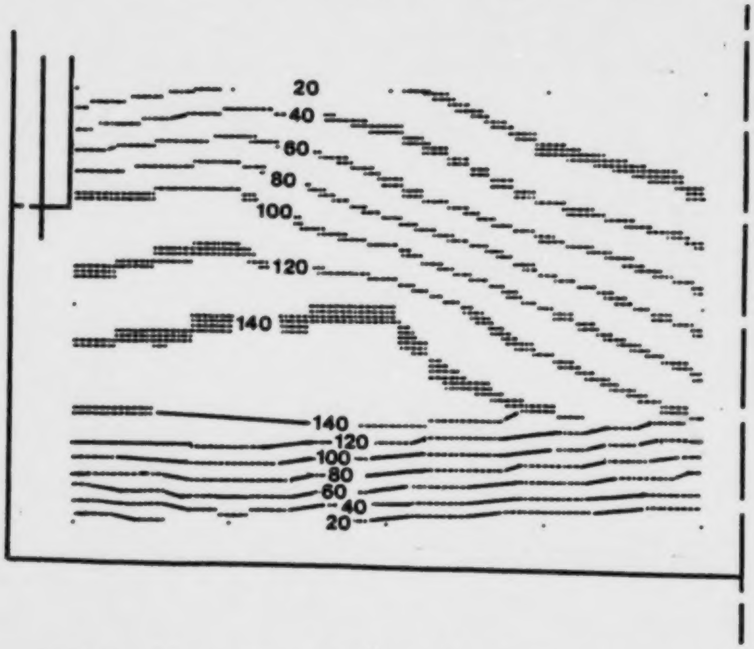


Figure 91. Radial distribution of the dye concentration in EBMUD secondary clarifier #11, 105 min after the start of continuous dye injection, 3 February 1979.

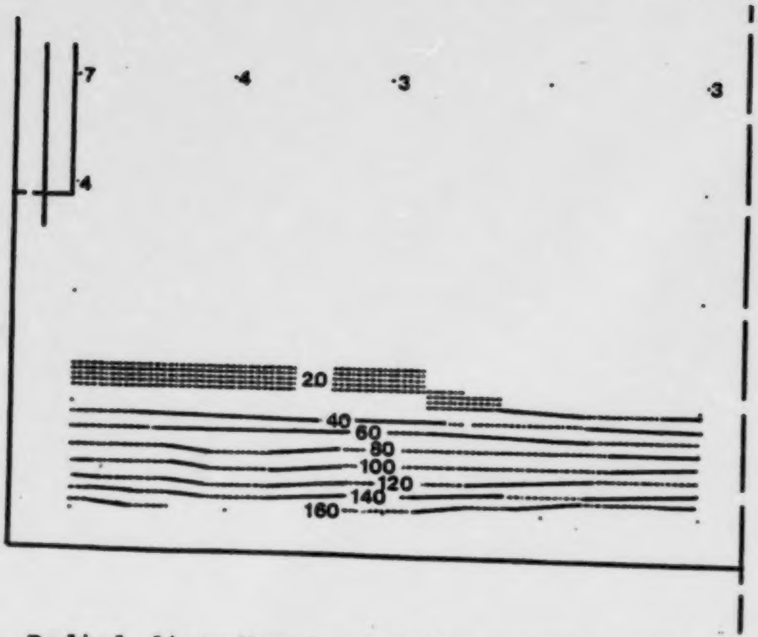


Figure 92. Radial distribution of the square-root of total suspended solids in EBMUD secondary clarifier #11, 3 February 1979.

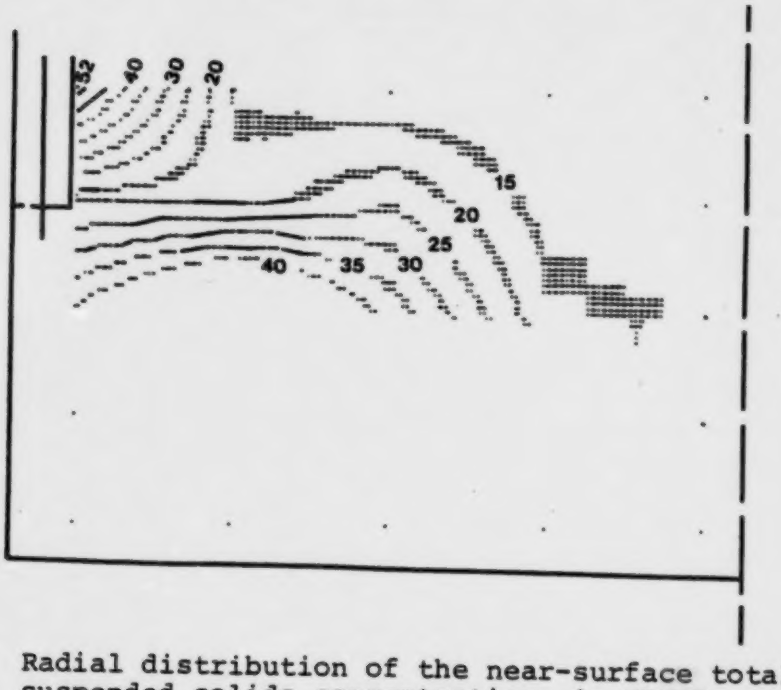


Figure 93. Radial distribution of the near-surface total suspended solids concentrations in EBMUD secondary clarifier #11, 3 February 1979.

No sharp upturn or rebound is noted. Rather, there is a gradual upflow, slightly more rapid at mid radius than at the periphery. Although Figure 92 shows that the higher solids concentrations (>400 mg/l) were smoothly distributed, a 52 mg/l concentration was measured in the sample nearest the overflow weir. (The value 7, posted, is the nearest integer to the square-root of 52.) Figure 93 presents the same solids distribution data differently. Lower concentration solids are posted and contoured directly rather than as square-roots, with a contour interval of 5 mg/l. This suggests that the 52 mg/l value may have been anomalous; the "source" of the higher concentration is not seen. By a peculiarity of the computer contour program, a maximum of 8 contour lines is printed, although the influence of higher concentrations is accounted for in the contour slopes. Raw data utilized for Figure 93 was identical to that used to generate Figure 92.

Test results at 100% of design overflow rate--A Multi-Point Dispersion Test was conducted on 31 January 1979. During the test, effluent rate was controlled at 10 mgd (38,000 m^3/d). This corresponds to a surface area overflow rate of 650 gpd/sq ft (26.48 $m^3/m2 \cdot d$). Underflow rate varied from 0.72 mgd (2730 m^3/d) to nearly zero. Blanket thickness remained fairly constant at 2.5 ft (0.76 m).

Physical data pertinent to the 100% Multi-Point Dispersion Test is summarized in Table 12. The six dispersion curves are shown as Figures 94 through 99.

TABLE 12. PHYSICAL DATA PERTINENT TO THE DISPERSION TEST ON EBMUD SECONDARY CLARIFIER #11 AT 100% OF DESIGN OVERFLOW RATE, 31 JANUARY 1979

Background fluorescence = 3.7 ppb
Tank volume = 1,610,000 gal
Effluent rate during test = 10 mgd
Underflow rate during test = variable, average 0.60 mgd
Retention time based on average influent rate, T_O = 219.0 min
500 ml of dye were used in test clarifier only
Flash mix fluorescence, C_O = 82.0 ppb

Weir Station	Relative Dye Mass Overflowing Weir Station	Median Retention Time for This Test (min)
A	0.786	159.2
B	0.708	173.8
C	0.809	150.4
D	0.709	142.5
E	0.737	139.1
F	0.695	142.8

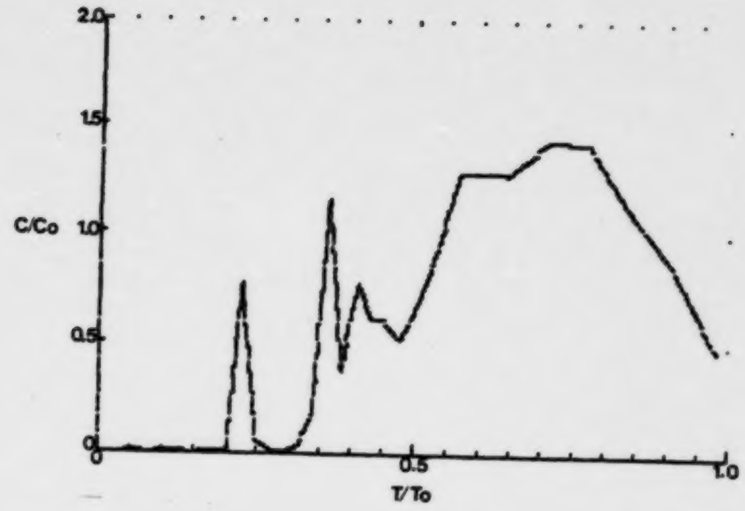


Figure 94. Results of the Multi-Point Dispersion Test for EBMUD secondary clarifier #11, weir station A, 31 January 1979.

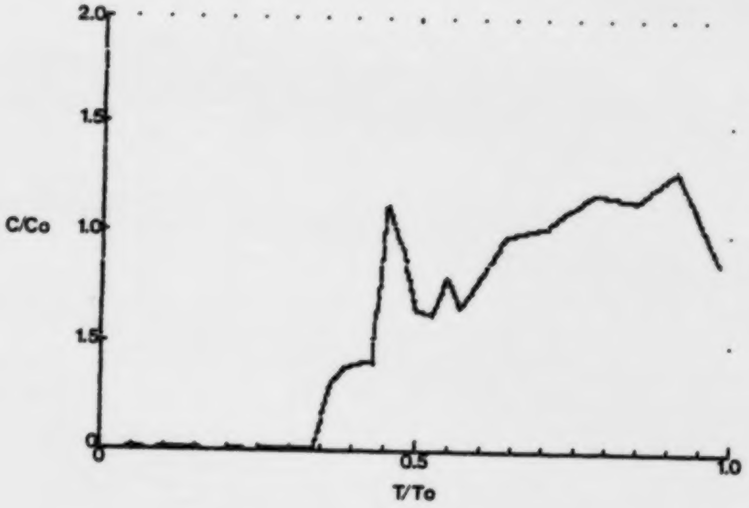


Figure 95. Results of the Multi-Point Dispersion Test for EBMUD secondary clarifier #11, weir station B, 31 January 1979.

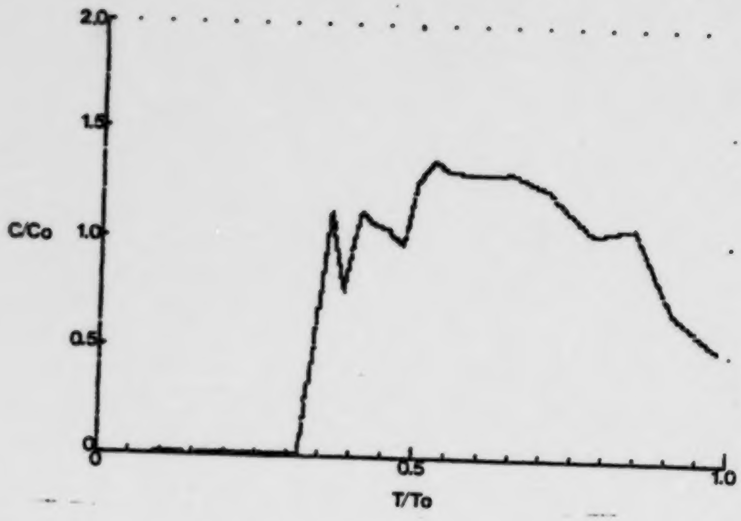


Figure 96. Results of the Multi-Point Dispersion Test for EBMUD secondary clarifier #11, weir station C, 31 January 1979.

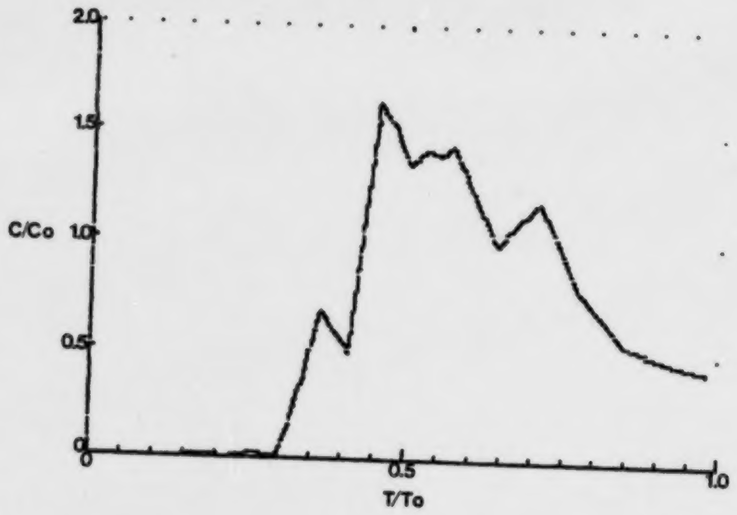


Figure 97. Results of the Multi-Point Dispersion Test for EBMUD secondary clarifier #11, weir station D, 31 January 1979.

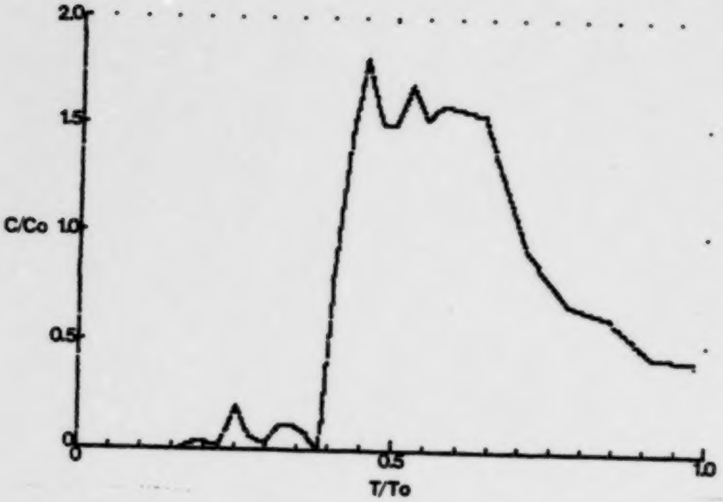


Figure 98. Results of the Multi-Point Dispersion Test for EBMUD secondary clarifier #11, weir station E, 31 January 1979.

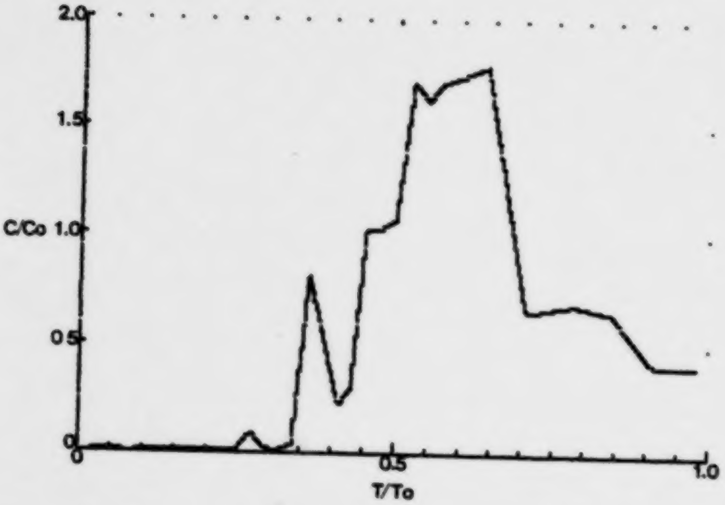


Figure 99. Results of the Multi-Point Dispersion Test for EBMUD secondary clarifier #11, weir station F, 31 January 1979.

Again, the areas under the curves are similar, but it is interesting to note that at design overflow rate, both the time of first dye passage and the time for 50% dye passage were significantly later (in non-dimensional time) than was noted at the lower flow rate. The two prominent peaks on Figure 94 occur 30 min apart. Sludge arm rotation period was 35.5 min. Sampling interval was 5 min; thus, the relationship between sludge arm rotation and dye peaks is uncertain.

Pertinent auxiliary data for 31 January 1979 are as follows:

Solids

1100 -	MLTSS	2500 mg/l
	Effluent TSS (grab)	14 mg/l
	SVI	38
1320 -	MLTSS	2500 mg/l
	Effluent TSS (grab)	22 mg/l
	SVI	42

During the Flow Pattern/Solids Distribution Test on 5 February 1979, the effluent rate was held reasonably constant at 10.5 mgd (39,700 m^3/d). This corresponds to a surface area overflow rate of 682 gpd/sq ft (27.78 $m^3/m^2\cdot d$). Underflow averaged 1.08 mgd (4090 m^3/d) and the blanket thickness was estimated at 2.6 ft (0.79 m). Dye injection, at a rate of 2.6 ml/min, followed by three sampling runs at bridge stations 1-5 resulted in the flow pattern time series, Figures 100 through 102 and the solids distribution plot, Figure 103.

The contoured data appear remarkably similar to those produced at 65% of design overflow rate. The solids, in Figure 103, are somewhat more diffuse than those shown in Figure 92. Otherwise, flow pattern conditions seem nearly identical.

Pertinent process data, from samples retrieved during the 5 February test, are as follows:

MLTSS - 3000 mg/l
Effluent TSS (grab) - 17 mg/l
SVI - 47

A Flow Pattern/Solids Distribution Test was completed on 1 February 1979 at an effluent rate of 10.6 mgd (40,100 m^3/d). This corresponds to a surface area overflow rate of 689 gpd/sq ft (28.1 $m^3/m^2\cdot d$). Underflow was 0.480 mgd (1817 m^3/d) with the blanket occupying approximately half the tank depth, or 7 ft (2.1 m).

Dye, injected at a rate of 4.5 ml/min produced the quite different flow pattern and solids distribution series, Figures 104 through 107. In Figure 104, dye seemed to progress smoothly

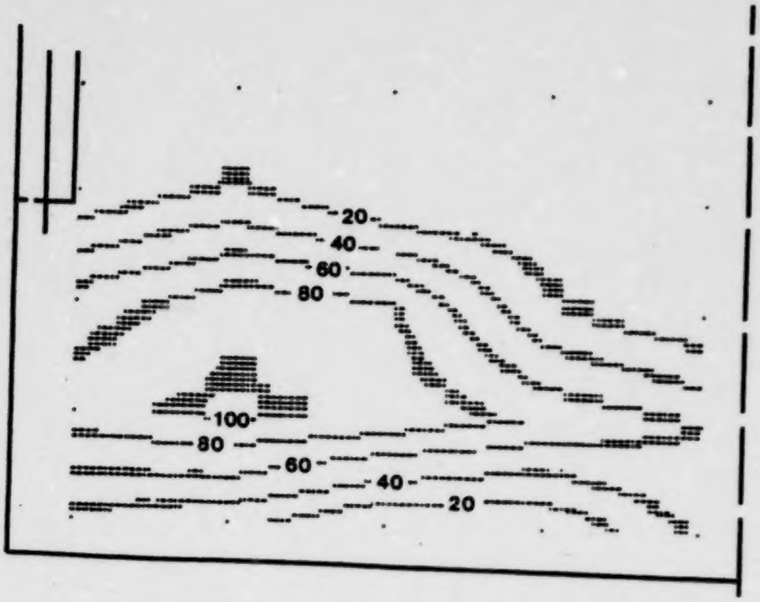


Figure 100. Radial distribution of the dye concentration in EBMUD secondary clarifier #11, 40 min after the start of continuous dye injection, 5 February 1979.

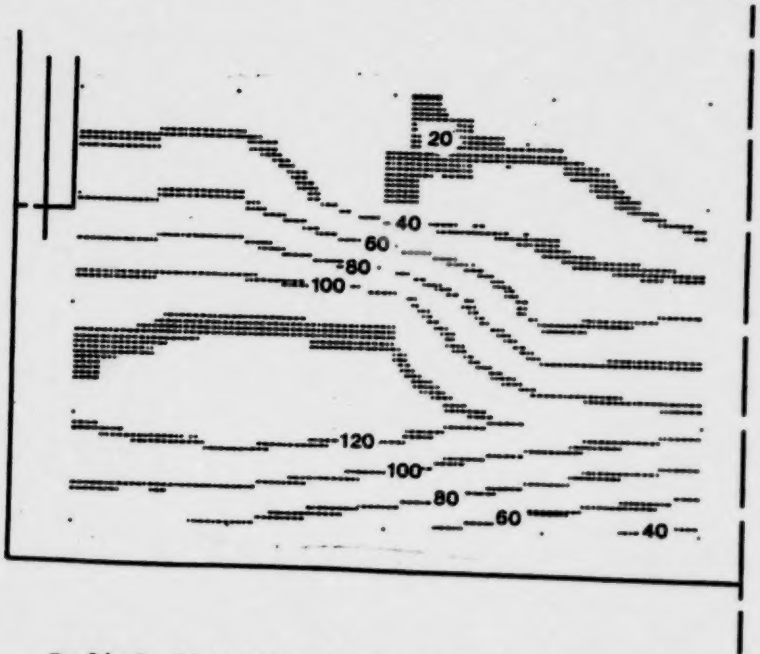


Figure 101. Radial distribution of the dye concentration in EBMUD secondary clarifier #11, 70 min after the start of continuous dye injection, 5 February 1979.

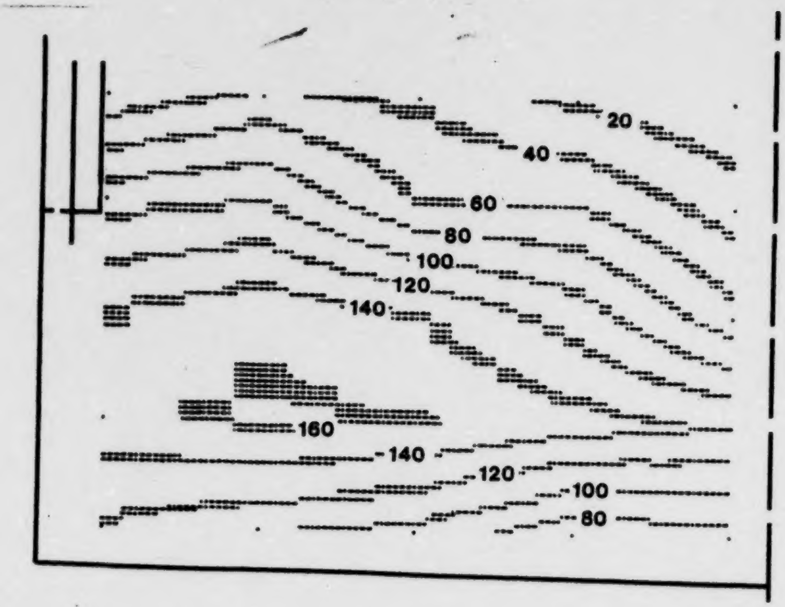


Figure 102. Radial distribution of the dye concentration in EBMUD secondary clarifier #11, 105 min after the start of continuous dye injection, 5 February 1979.

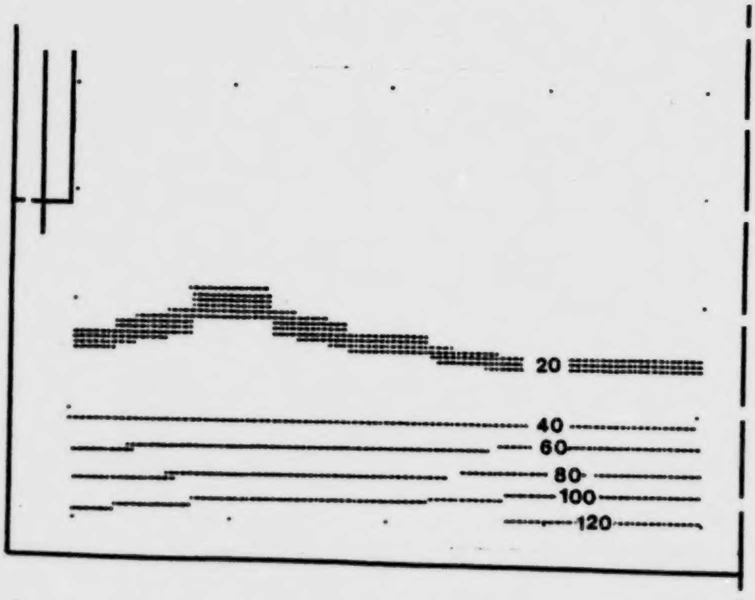
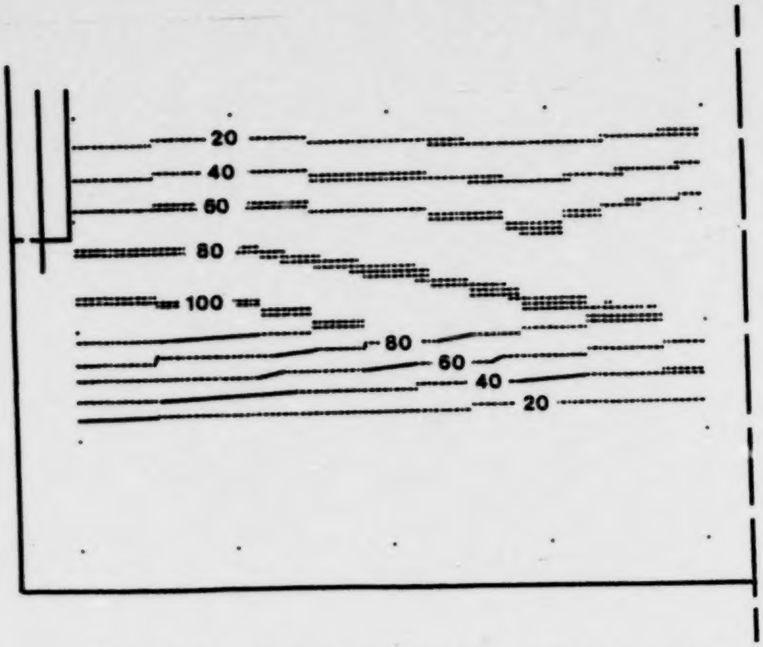


Figure 103. Radial distribution of the square-root of total suspended solids in EBMUD secondary clarifier #11, 5 February 1979.



ïgure 104. Radial distribution of the dye concentration in EBMUD secondary clarifier #11, 36 min after the start of continuous dye injection, 1 February 1979.

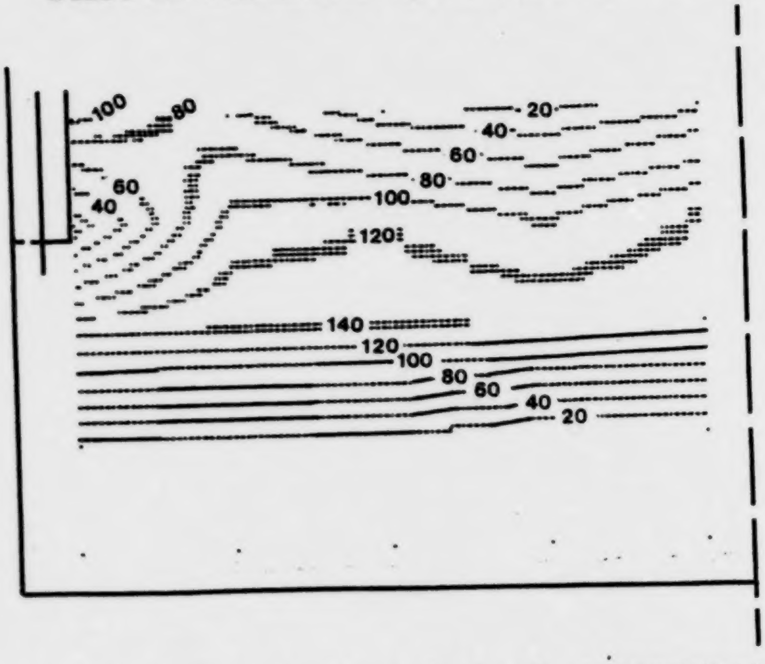


Figure 105. Radial distribution of the dye concentration in EBMUD secondary clarifier #11, 71 min after the start of continuous dye injection, 1 February 1979.

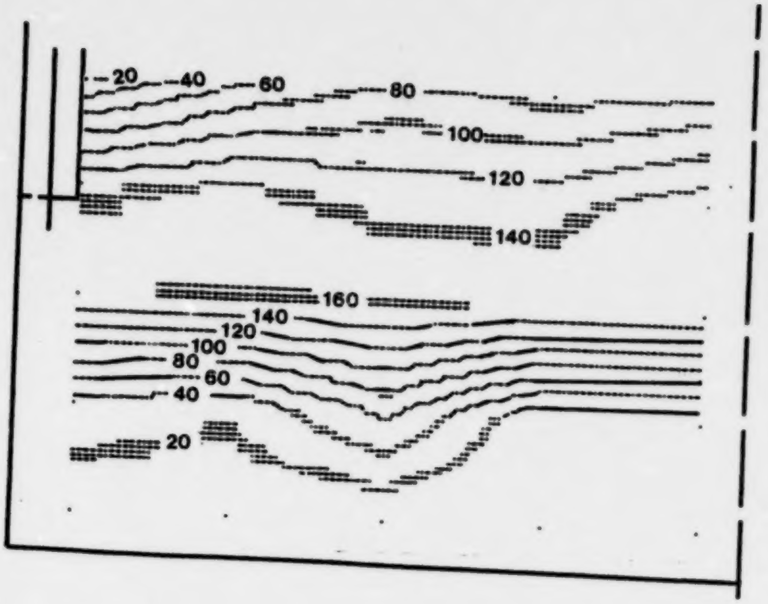


Figure 106. Radial distribution of the dye concentration in EBMUD secondary clarifier #11, 106 min after the start of continuous dye injection, 1 February 1979.

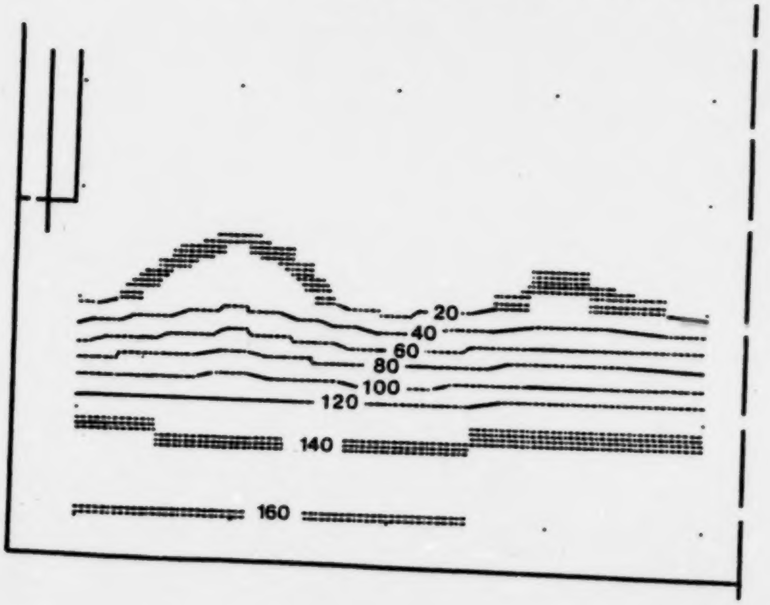


Figure 107. Radial distribution of the square-root of total suspended solids in EBMUD secondary clarifier #11, 1 February 1979.

toward the tank center. But, in Figure 105, turbulent eddies appear to have formed, with a relatively high dye concentration overflowing the weir. The condition is caused, perhaps, by the smaller area available for forward flow, between the sludge blanket and the inlet baffle. Similar disturbances have been noted in center feed circular clarifiers at Stamford and elsewhere[4] under high blanket conditions.

Pertinent process data, from samples retrieved during the 1 February test, are as follows:

MLTSS -	4000 mg/l
Effluent TSS (grab) -	26 mg/l
SVI -	41

Test results at 150% of design overflow rate--A Multi-Point Dispersion Test was conducted on 3 April 1979. During the test, operators became concerned about excessive solids carryover and the flow rate was decreased after 1.5 hours. Effluent rate was highly variable as illustrated in Figure 108, a tracing from the clarifier #11 electromagnetic effluent rate meter's record.

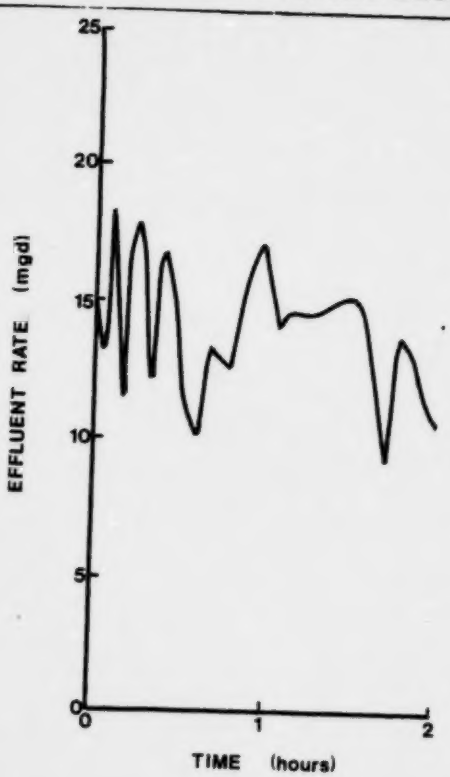


Figure 108. Effluent flow record from EBMUD secondary clarifier #11 during the Multi-Point Dispersion Test, 3 April 1979.

For the sake of calculation, the "typical" value during the first 1.5 hours, 15 mgd (57,000 m^3/d) was used. This corresponds to a surface area overflow rate of 974 gpd/sq ft (39.68 $m^3/m^2 \cdot d$). Underflow rate was fairly constant at 3.120 mgd (11,810 m^3/d) for the first 1.6 hours, then dropped to 0.720 mgd (2725 m^3/d). Again, a "typical" value, 3.0 mgd (11,400 m^3/d) was selected for the purpose of calculation. The sludge blanket was estimated to be 1.5 ft (0.5 m) thick although it will be shown in the results of the Flow Pattern Solids Distribution Test of 4 April, to follow, that blanket thickness at a given sampling location may have little meaning.

Physical data pertinent to the 150% Multi-Point Dispersion Test is summarized in Table 13. Sampling interval for weir stations A-E was 5 min. Sampling interval at weir station F was 2.5 min.

TABLE 13. PHYSICAL DATA PERTINENT TO THE DISPERSION TEST ON EBMUD SECONDARY CLARIFIER #11 AT 150% OF DESIGN OVERFLOW RATE, 3 APRIL 1979

Background fluorescence = 4.6 ppb
Tank volume = 1,610,000 gal
Typical effluent rate during test = 15 mgd - highly variable
Typical underflow rate during test = 3.0 mgd
Retention time based on influent rate, T_o = 129.0 min
750 ml of dye added to test clarifier only
Flash mix fluorescence, C_o = 122.9 ppb

Weir Station	Relative Dye Mass Overflowing Weir Station	Median Retention Time for This Test (min)
A	0.543	79.2
B	0.483	85.1
C	0.678	50.8
D	0.167	95.9
E	0.466	83.8
F	0.384	89.7

The six dispersion curves are presented in Figures 109 through 114.

Pertinent laboratory data for the 3 April 1979 dispersion test are as follows:

Solids	
MLTSS	2530 mg/l
Effluent TSS (grab)	32 mg/l
SVI	50

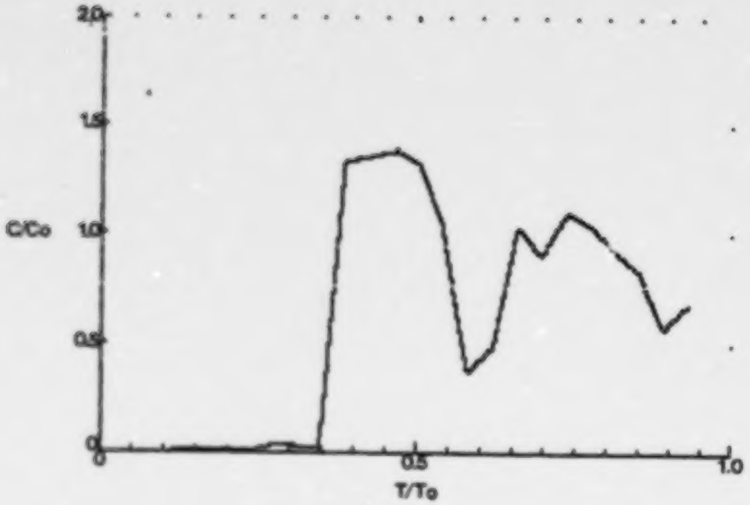


Figure 109. Results of the Multi-Point Dispersion Test for EBMUD secondary clarifier #11, weir station A, 3 April 1979.

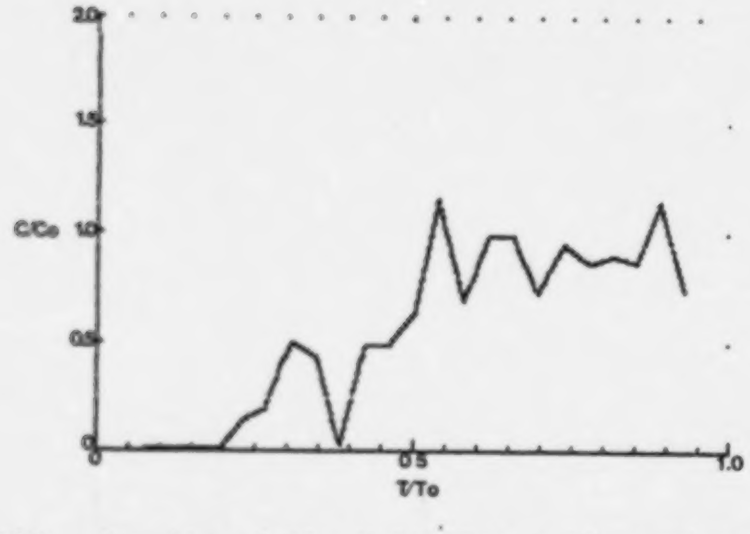


Figure 110. Results of the Multi-Point Dispersion Test for EBMUD secondary clarifier #11, weir station B, 3 April 1979.

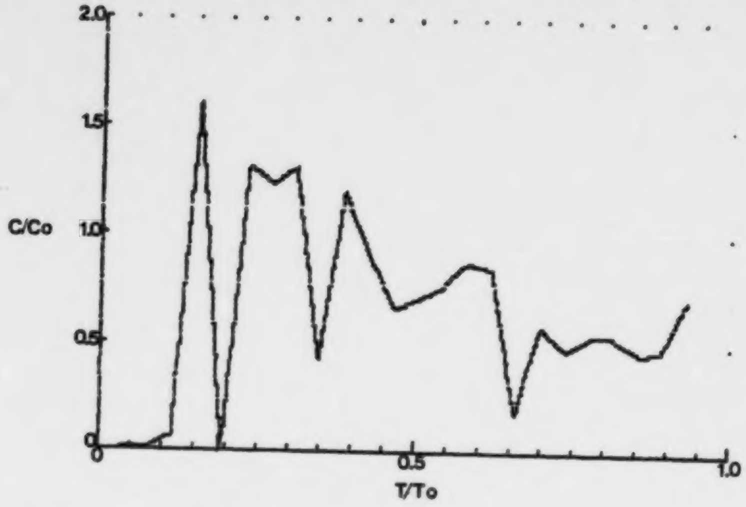


Figure 111. Results of the Multi-Point Dispersion Test for EBMUD secondary clarifier #11, weir station C, 3 April 1979.

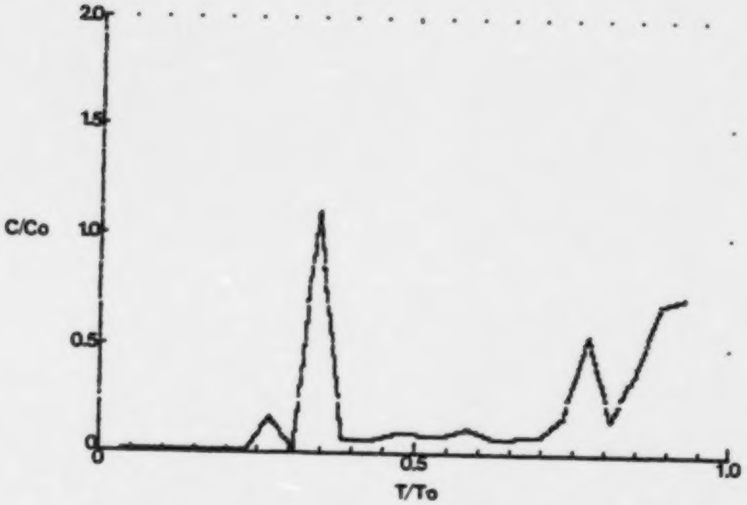


Figure 112. Results of the Multi-Point Dispersion Test for EBMUD secondary clarifier #11, weir station D, 3 April 1979.

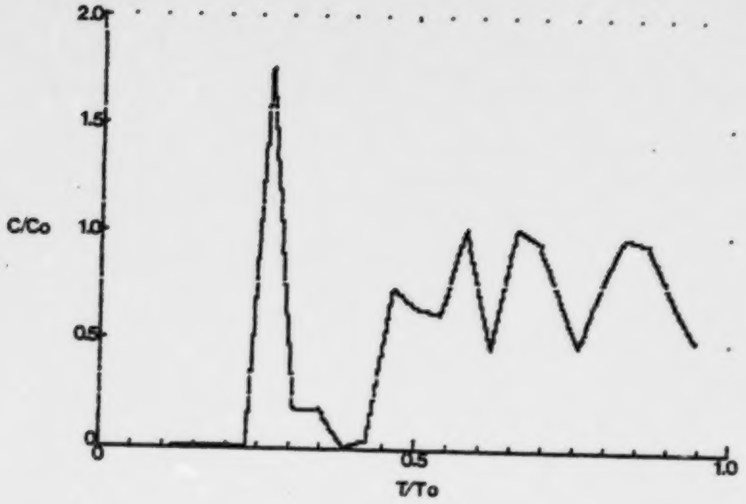


Figure 113. Results of the Multi-Point Dispersion Test for EBMUD secondary clarifier #11, weir station E, 3 April 1979.

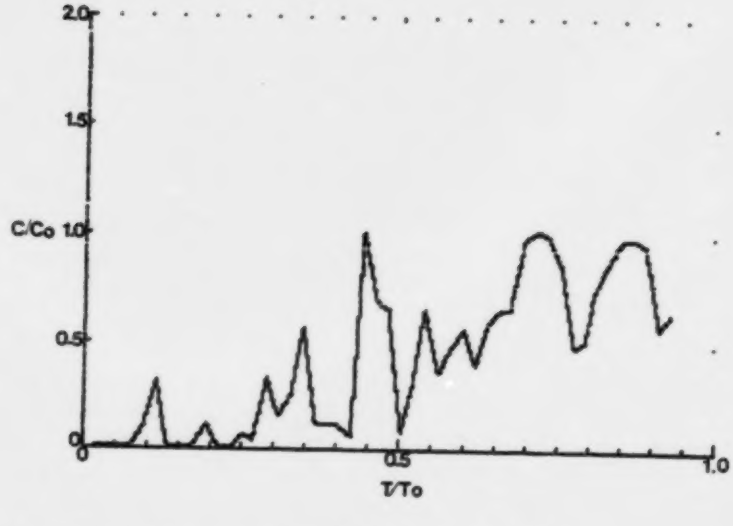


Figure 114. Results of the Multi-Point Dispersion Test for EBMUD secondary clarifier #11, weir station F, 3 April 1979.

The dispersion data of 3 April, Table 13 and Figures 109 through 114, suggested a flow imbalance. Additionally, a persistently high surface turbidity was observed in the general vicinity of stations 8, 9, and 10. (See Figure 82.) Stations 6 through 10 were established for the first time in this study to discover the reasons for the apparent solids disturbance along this line.

A Flow Pattern Solids Distribution Test was conducted on 4 April 1979 along pseudo-diametric cross-section H-H. During this test, effluent rate was held at a fairly constant 14.8 mgd (56,020 m^3/d); the wide fluctuations in flow rate illustrated in Figure 108 were not experienced. This effluent rate corresponds to a surface area overflow rate of 961 gpd/sq ft (39.15 $m3/m2 \cdot d$). Underflow was constant at 1.8 mgd (6800 m^3/d). Dye injection, at a continuous rate of 7.5 ml/min, followed by three rather lengthy sampling runs, from 22-30 min duration each, resulted in the flow pattern time series, Figures 115 through 117 and the solids distribution plot, Figure 118. The order of sample retrieval in this series was left to right.

Pertinent auxiliary data for 4 April 1979 are as follows:

Solids

MLTSS	1950 mg/l
Effluent TSS (grab)	69 mg/l
SVI	64

The contour plots may be interpreted as follows: In Figure 115, the highest dye concentration appears at bottom-center. Secondary dye sources appear at the right-hand and left-hand sides of the illustration, emanating from the peripheral inlet channel. The dye in the center of the illustration must have originated from a direction outside the sampling section, H-H. Figure 116 shows a convergence of the center and right-hand dye sources at "C". Finally, in Figure 117, the convergence has resulted in upwelling on the right-hand side, near the weir. This upwelling is confirmed in the solids distribution plot, Figure 118 and by observations of high surface turbidity in this region on this day and the previous day. On the bottom, solids appear to be relatively thick on the right-hand side of Figure 118.

The key to the hydraulic imbalance in this clarifier at high flow rates was believed to be the mixed liquor flow control butterfly valve. As shown in the partial plan view of clarifier #11, Figure 119, a butterfly valve controlled mixed liquor feed to the clarifier's peripheral inlet distribution channel. When partially closed, as shown, a greater flow rate was induced in the inlet distribution channel in the clockwise direction, due to the "steering vane" effect of the valve. On careful observation, it was seen that a "standing wave" resided in the region

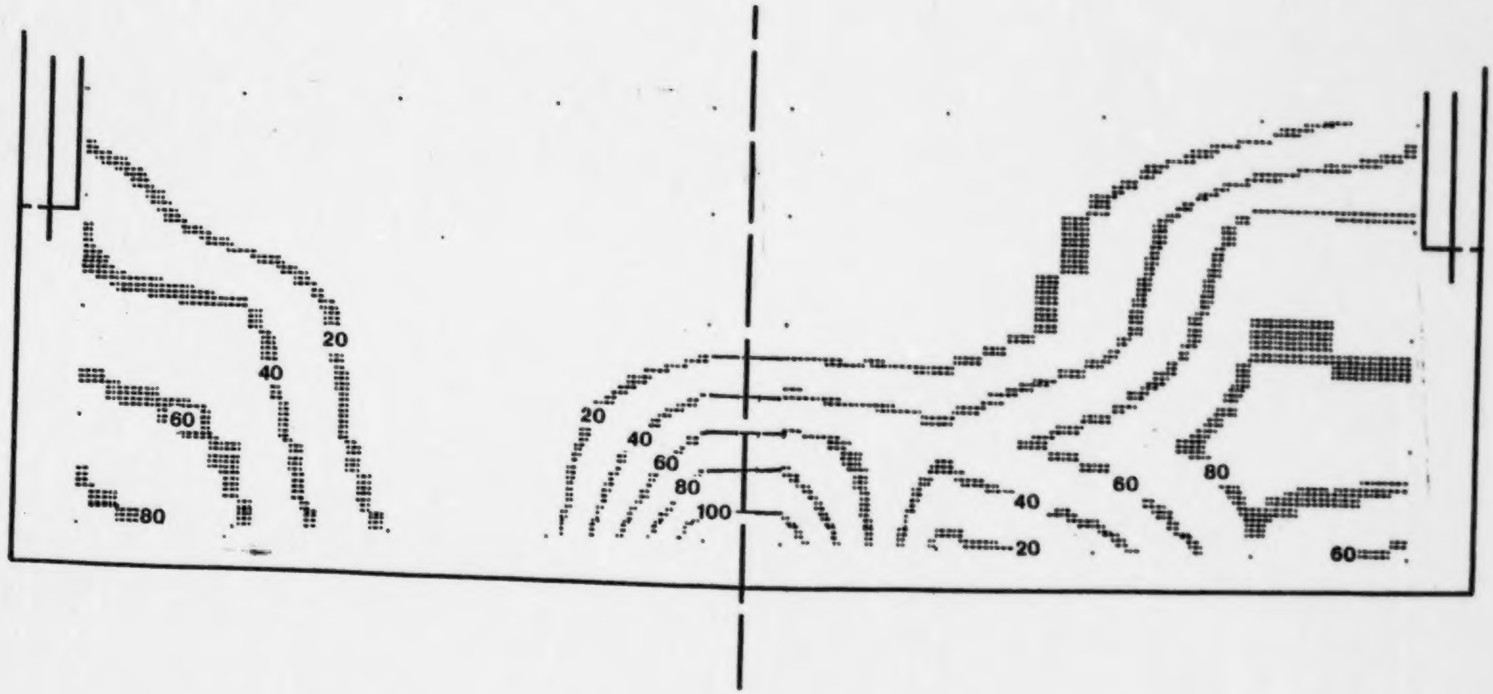


Figure 115. Distribution of dye concentration in cross-section H-H of EBMUD secondary clarifier #11, 23.5 min after the start of continuous dye injection, 4 April 1979.

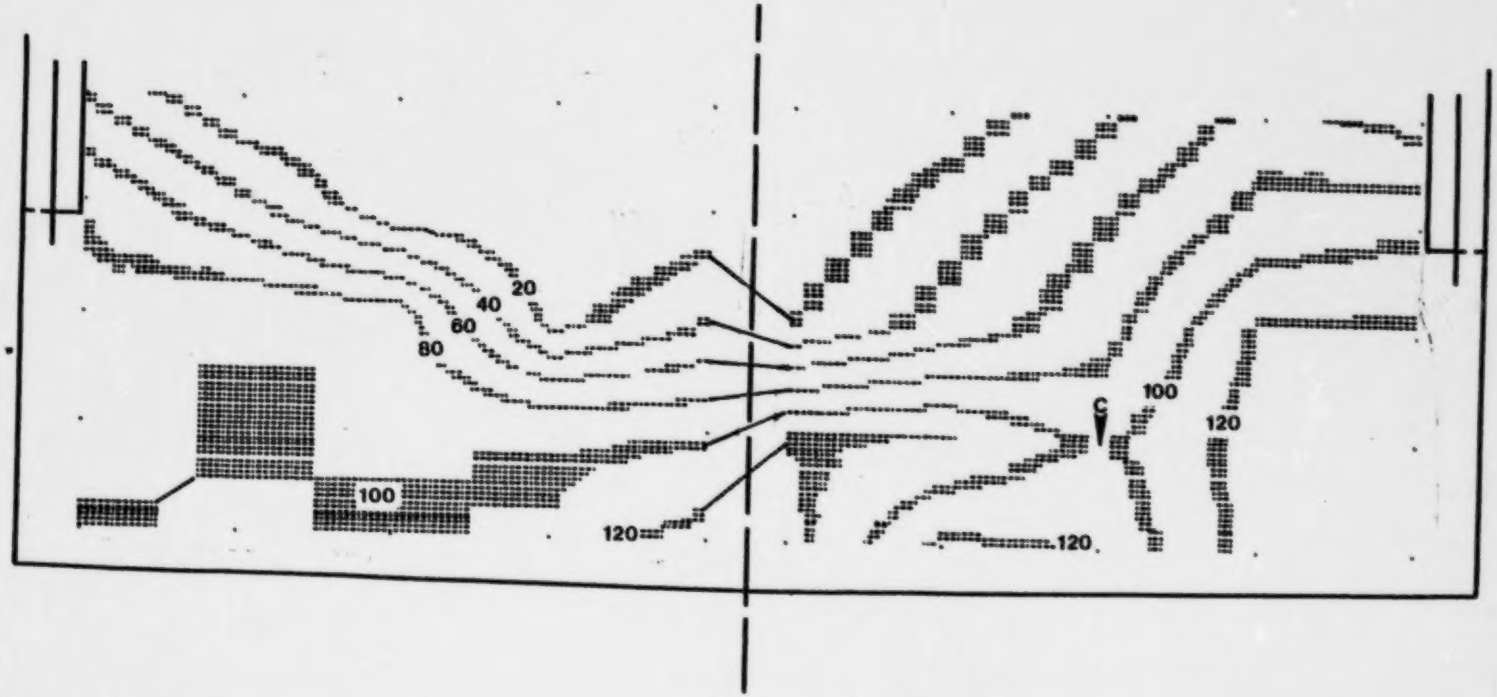


Figure 116. Distribution of dye concentration in cross-section H-H of EBMUD secondary clarifier #11, 57 min after the start of continuous dye injection, 4 April 1979. Point "C" is explained in the text.

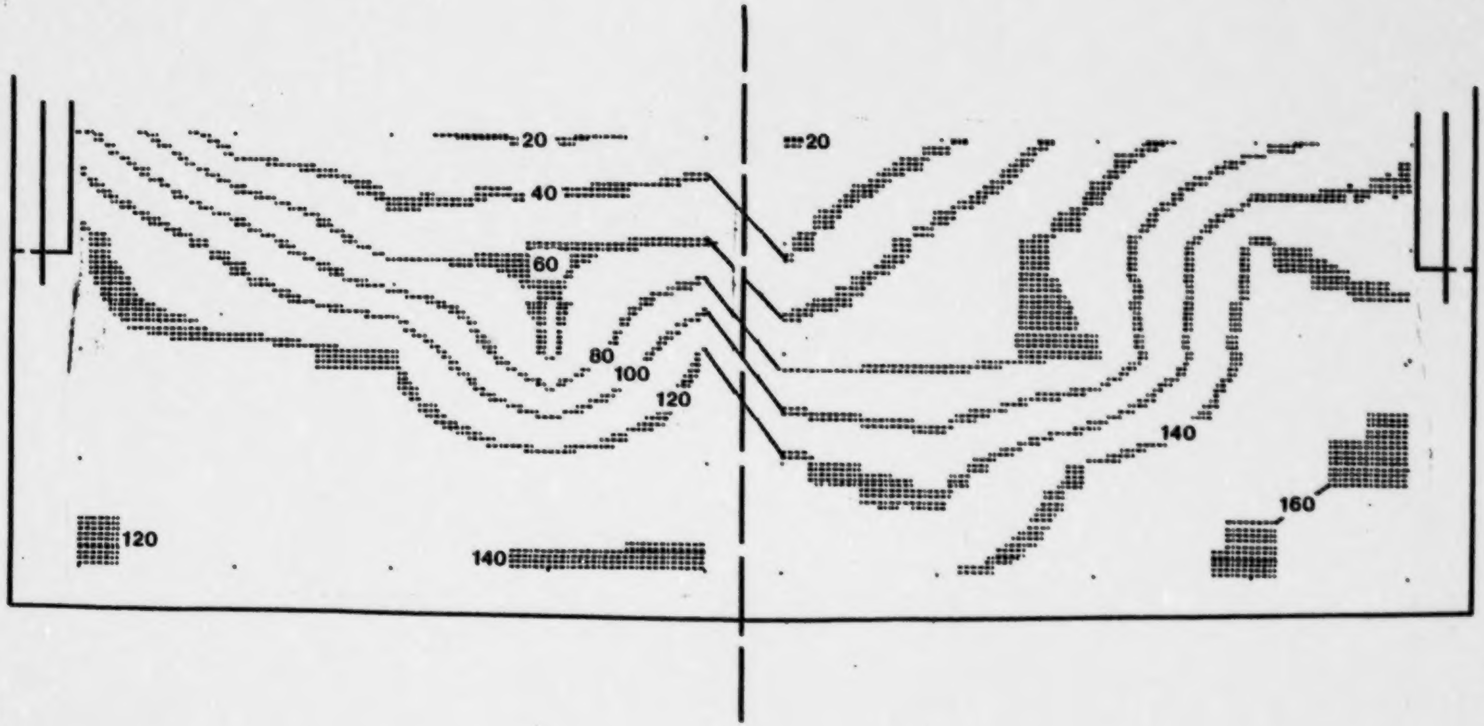


Figure 117. Distribution of dye concentration in cross-section H-H of EBMUD secondary clarifier #11, 96 min after the start of continuous dye injection, 4 April 1979.

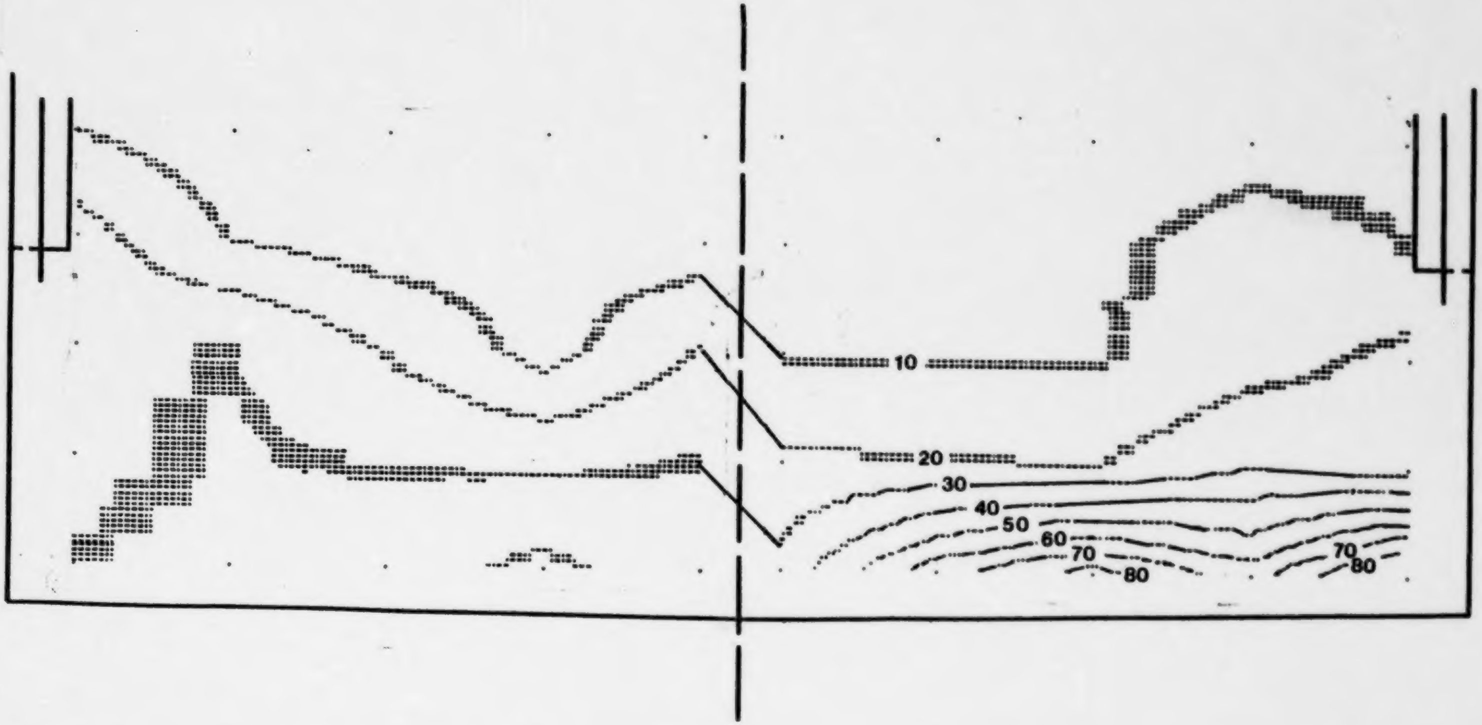


Figure 118. Distribution of the square-root of total suspended solids in cross-section H-H of EBMUD secondary clarifier #11, 4 April 1979.

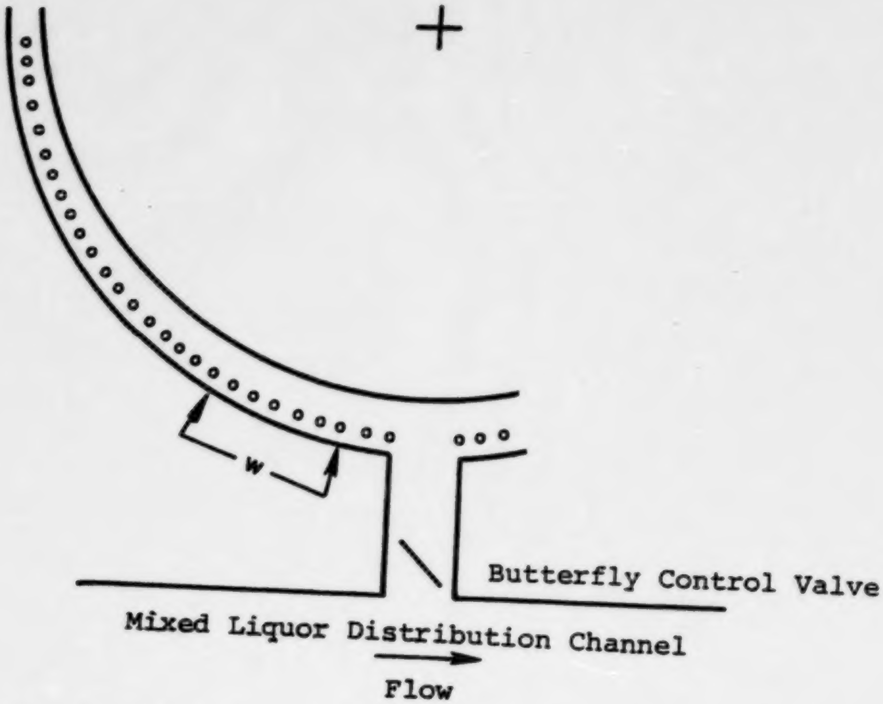


Figure 119. Partial plan view of EBMUD secondary clarifier #11 showing the mixed liquor distribution channel common to all secondaries, the butterfly flow control valve and the clarifier's inlet distribution channel with multiple inlet ports. Region "W" is explained in the text.

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designated "W". The additional head from the "wave", imparting greater flow to the inlet ports in the vicinity of W, is believed to be the origin of a relatively high flow rate jet which first appears in the center of cross-section H-H, Figure 115. Station 1 of section H-H is just counter-clockwise of region W, thus, the core of the jet would not have been detected near station 1.

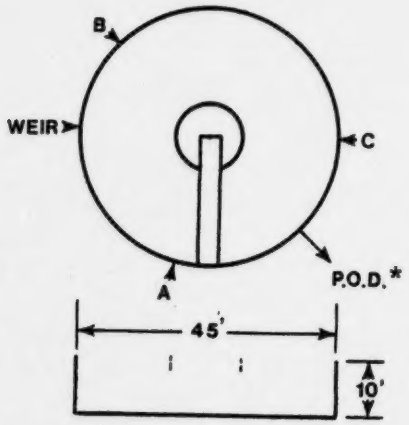
The clarifier exhibited hydraulic problems only at a high flow rate with a partially closed butterfly control valve. If it can be anticipated that the control valve is normally only partially open, then a relatively simple solution to the problem of imbalance would be to plug selected inlet ports in the vicinity of the "standing wave". The clarifier designer has recommended specific ports to be plugged to compensate for the observed imbalance. It is estimated by the principal investigator that plugging the ports, as recommended, would enable the treatment plant to utilize fewer secondary clarifiers at increased flow rates and still maintain a satisfactory effluent quality.

Oakland, California East Bay Municipal Utility District (EBMUD)-Process Water Plant

Facility Description--

The study at the EBMUD process water plant was limited to one day. The facility presented the opportunity for a brief look at characteristics of a small circular secondary of common design while already on-site for the main plant study, just presented.

The EBMUD process water plant is an oxygen activated sludge facility, shown as units 3-6 in the main plant process schematic, Figure 81. The single secondary clarifier is a center feed, peripheral overflow unit, 45 ft (13.7 m) in diameter, with a sidewater depth of 10 ft (3.0 m). Bottom slope is very slight. Design effluent rate for the unit is 1.0 mgd ($3.8 m^3/d$). There are four inlet ports within a feedwell which is 12 ft (3.7 m) in diameter. Feedwell depth was not determined. Sludge is removed by a riser pipe and scraper mechanism which rotates at a speed of 1 revolution per 29 min. A scum skimmer and sump are provided. A plan and elevation drawing of the clarifier is presented as Figure 120.



*Point of Discharge

Figure 120. Plan and elevation of the East Bay Municipal utility District's process water secondary. Feedwell depth was not determined.

Hydraulic Test Results--

A Multi-Point Dispersion Test was conducted on 6 February 1979. During the test, effluent rate was 0.35 mgd (1320 m^3/d). This corresponds to a surface area overflow rate of 220 gpd/sq ft (8.96 $m^3/m^2 \cdot d$). Underflow was 0.23 mgd (860 m^3/d). The blanket was determined to be 0.5 ft (0.2 m) in thickness. Sampling interval was 5 min at station A and 15 min at stations B and C. Pertinent laboratory data for the time of the dispersion test is shown in Table 15.

Physical data pertinent to the Multi-Point Dispersion Test is presented in Table 14.

TABLE 14. PHYSICAL DATA PERTINENT TO THE DISPERSION TEST ON THE EBMUD PROCESS WATER SECONDARY CLARIFIER, 6 FEBRUARY 1979

Background fluorescence = 1.9 ppb
Tank volume = 11,900 gal
Effluent rate during test = 0.35 mgd
Underflow rate during test = 0.23 mgd
Retention time based on influent rate, T_o = 297.4 min
50 ml of dye were used in test clarifier only
Flash mix fluorescence, C_o = 111 ppb

Weir Station	Relative Dye Mass Overflowing Weir Station	Median Retention Time for This Test (min)
A	0.544	126.8
B	0.571	114.6
C	0.507	130.9

TABLE 15. PROCESS DATA ON THE TEST CLARIFIER, EBMUD PROCESS WATER, 6 FEBRUARY 1979

MLTSS	3900 mg/l
Effluent TSS	19 mg/l

Mixed liquor settling curve:

Time (min)	Settled Sludge Volume (ml/l)	
5	330	
10	250	
15	195	
20	210	
30	195	SVI = 50
60	185	

The three dispersion curves are presented in Figures 121 through 123.

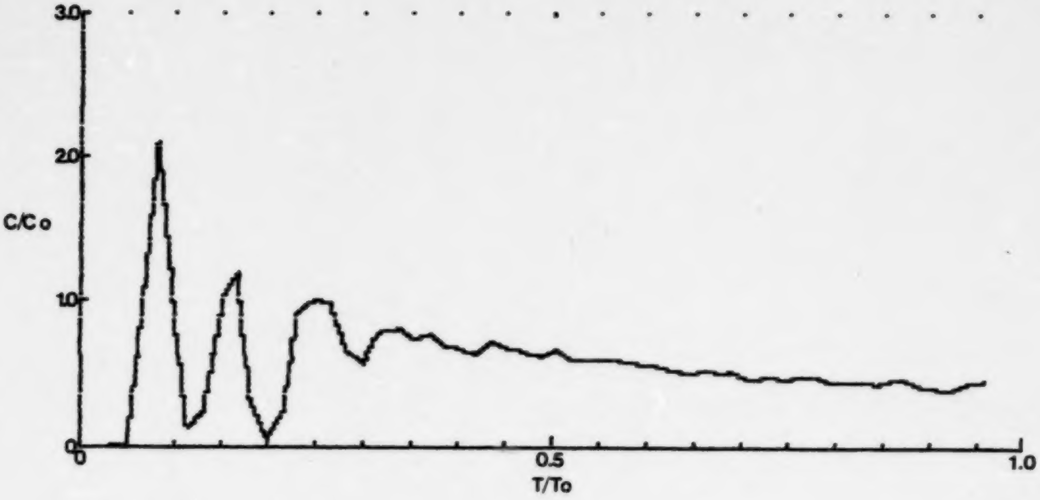


Figure 121. Results of the Multi-Point Dispersion Test for the EBMUD process water secondary clarifier, weir station A, 6 February 1979.

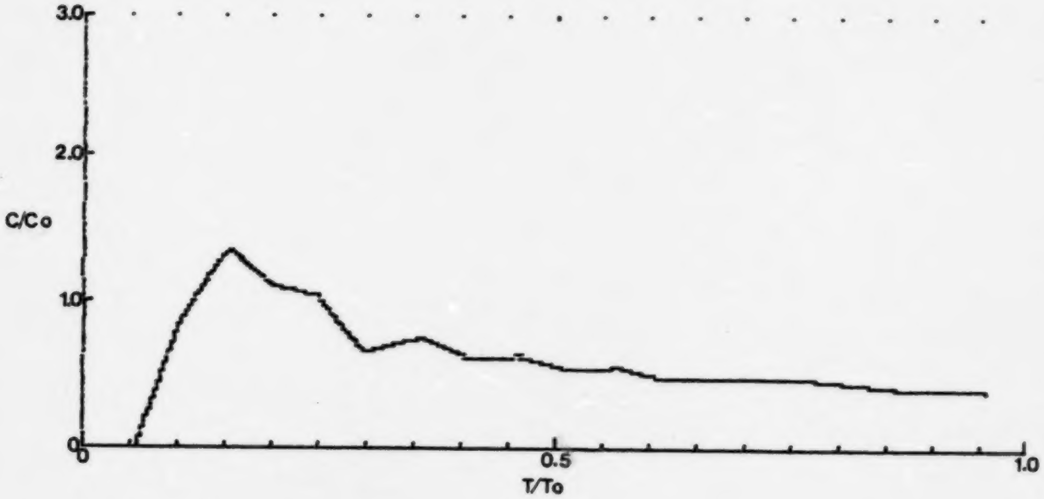


Figure 122. Results of the Multi-Point Dispersion Test for the EBMUD process water secondary clarifier, weir station B, 6 February 1979.

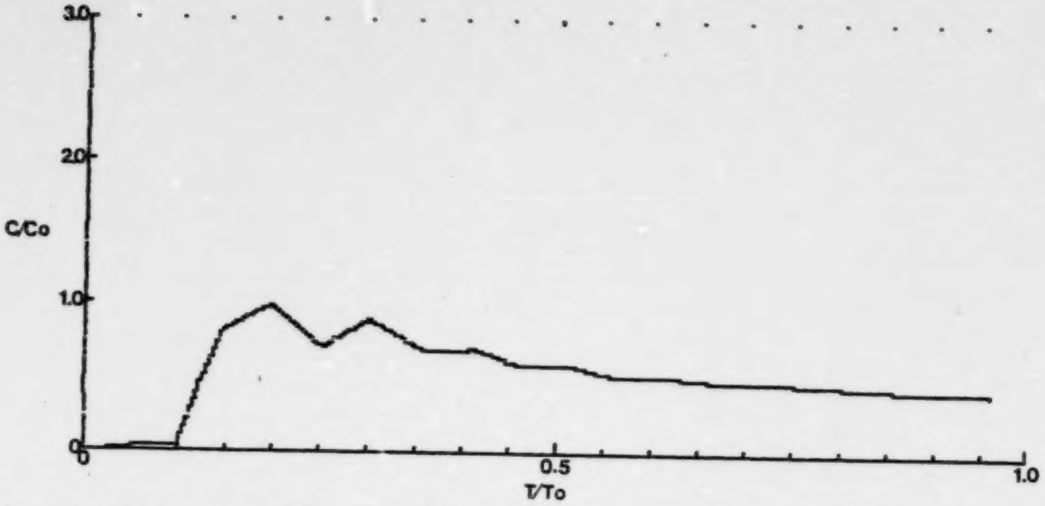


Figure 123. Results of the Multi-Point Dispersion Test for the EBMUD process water secondary clarifier, weir station C, 6 February 1979.

Orange County, Florida

Facility Description--

Limited hydraulic studies were conducted at the Sand Lake Road wastewater treatment plant in Orange County, near Orlando, Florida. Although useful results were obtained, no modifications could be accomplished within the scope of this project.

The Sand Lake Road plant is an air activated sludge facility which was, in September 1979, operating at about 1/4 of design capacity. A process schematic is presented in Figure 124.

The plant has four large rectangular clarifiers, shown in Figure 125, each 206 ft (62.8 m) long by 75 ft (22.8 m) wide, with a water depth of 12.9 ft (3.93 m). Design effluent rate for each unit is 7.5 mgd (28,400 m^3/d). There are four inlet ports at about mid-depth in each tank. A single deflection baffle immediately downstream of the inlet ports directs flow downward.

Sludge is removed by traveling bridges with eight air-lift pumps. The air-lifts operate only during the 24 min time of bridge travel from the outlet (weir) end to the inlet end. Airlifts are shut down and the suction tubes raised during the 12 min bridge travel time back to the outlet end of the tank. The four bridges are not synchronized, so that flow rates throughout the plant, and at the point of discharge, are highly variable. Scum is scraped to a trough at the inlet end on each bridge travel cycle.

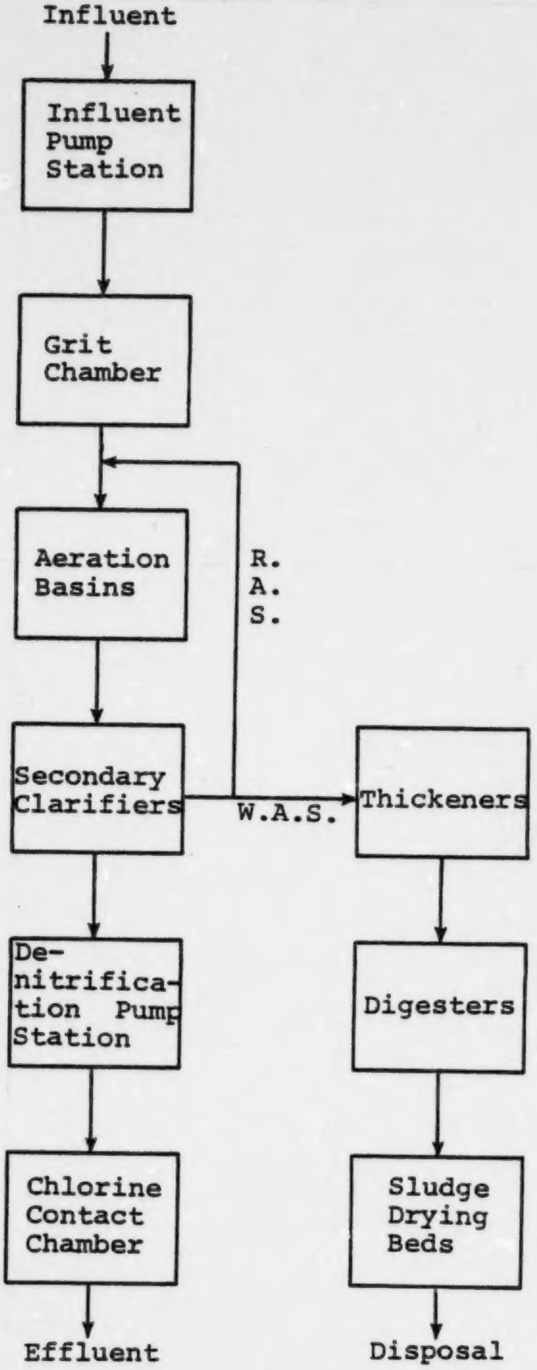

Influent
Influent Pump Station
Grit Chamber
Aeration Basins
R. A. S.
Secondary Clarifiers
W.A.S.
Thickeners
De-nitrification Pump Station
Digesters
Chlorine Contact Chamber
Sludge Drying Beds
Effluent
Disposal

Figure 124. Process schematic for the Orange County, FL, Sand Lake wastewater treatment plant.

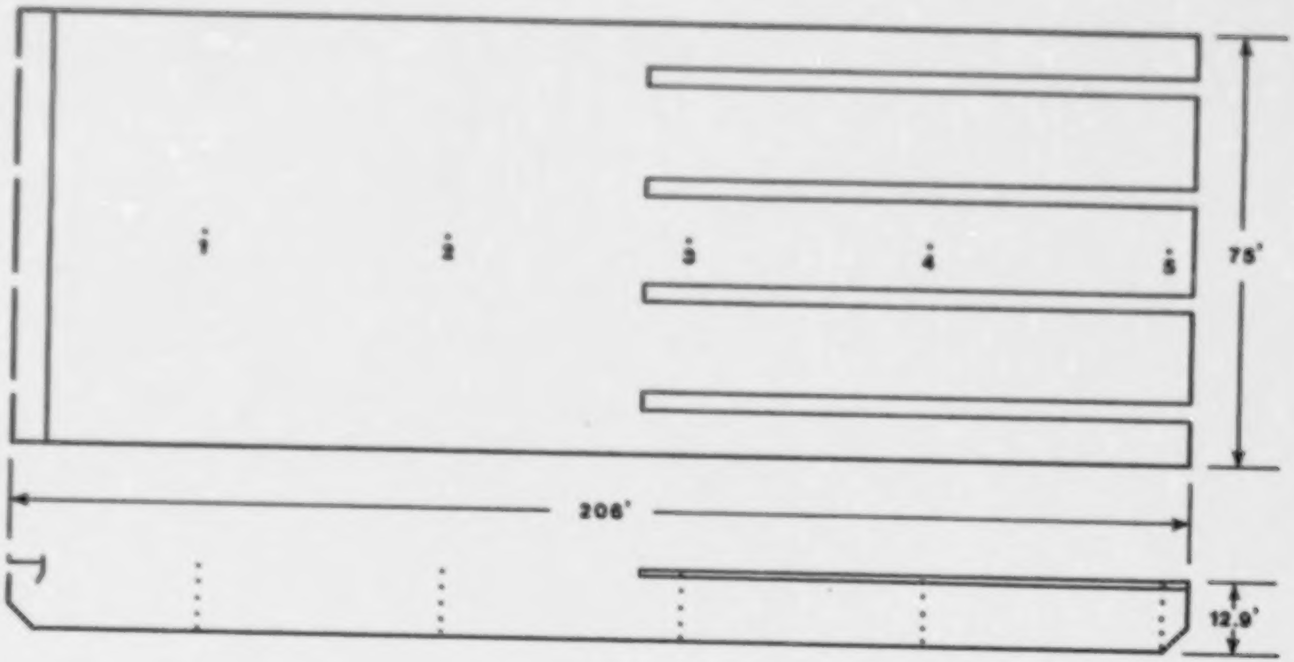

1
2
3
4
5
75'
206'
12.9'

Figure 125. Plan and elevation of Sand Lake Road secondary clarifier #1.

Longitudinal "finger weirs" cover approximately half of the tank's surface at the end furthest from the inlet ports. Total weir length is 762 ft (232.2 m).

Individual return sludge flow meters (level guages) were available on each clarifier, but none were functioning during the study. A single, propeller type flowmeter measured only total plant effluent rate, just downstream of the clarifiers.

Mixed liquor may be fed to the four secondaries by a common channel from all aeration basins or split into two separate trains. During this study, only half the plant was operating. There is no effective means of balancing flows to the individual secondaries. Flow to the downstream clarifier on the common mixed liquor channel appeared to be greater than flow to the upstream unit when both were operating. The extreme variability in clarifier overflow rate, due to intermittent sludge removal practice, made it difficult to confirm this observation.

Hydraulic Test Results--

Before beginning the test series, weirs on secondary #1 were leveled on the still-water surface, with the unit shut down. Several long sections of weir were found to differ in elevation from other sections by as much as 0.75 inch (19 mm). Secondary clarifier #1 was then used for all subsequent tests.

A Point of Discharge Dispersion Test was conducted on 19 September 1979. The entire plant flow was diverted to the test clarifier. Effluent rate during the test averaged 9.45 mgd (35,770 m^3/d), about 126% of design hydraulic capacity. This corresponds to a surface area overflow rate of 611 gpd/sq ft (24.89 $m^3/m^2 \cdot d$). Underflow rate was estimated from plant flow records to be 3.09 mgd (11,700 m^3/d). The method for estimating underflow rate will be discussed later. The sludge blanket was not measured.

Table 16 includes the pertinent information used for calculation of dispersion characteristics. The single dispersion curve is shown in Figure 126.

TABLE 16. PHYSICAL DATA PERTINENT TO THE DISPERSION TEST ON SAND LAKE ROAD SECONDARY CLARIFIER #1, 19 SEPTEMBER 1979

Background fluorescence = 1.9 ppb
Tank volume = 1,450,000 gal
Average effluent rate during test = 9.45 mgd
Estimated average underflow rate during test = 3.09 mgd
Retention time based on influent rate, T_o = 166.2 min
1505 ml of dye added to test clarifier only
Flash mix fluorescence, C_o = 274.7 ppb

Measurement Location	Non-Dimensional Area Under Dispersion Curve	Median Retention Time for This Test (min)
Point of Discharge	0.407	101.4

Laboratory data for the day of the dispersion test is presented in Table 17.

It is useful to note that during the dispersion test, dye first appeared at the surface in the general region illustrated by shading in Figure 127. The figure shows the appearance of the surface 23 min after dye release. On this and other test days, the same region was seen to be outgassing, with small bubbles breaking at the surface. Occasionally, a higher surface turbidity could also be seen in this locale.

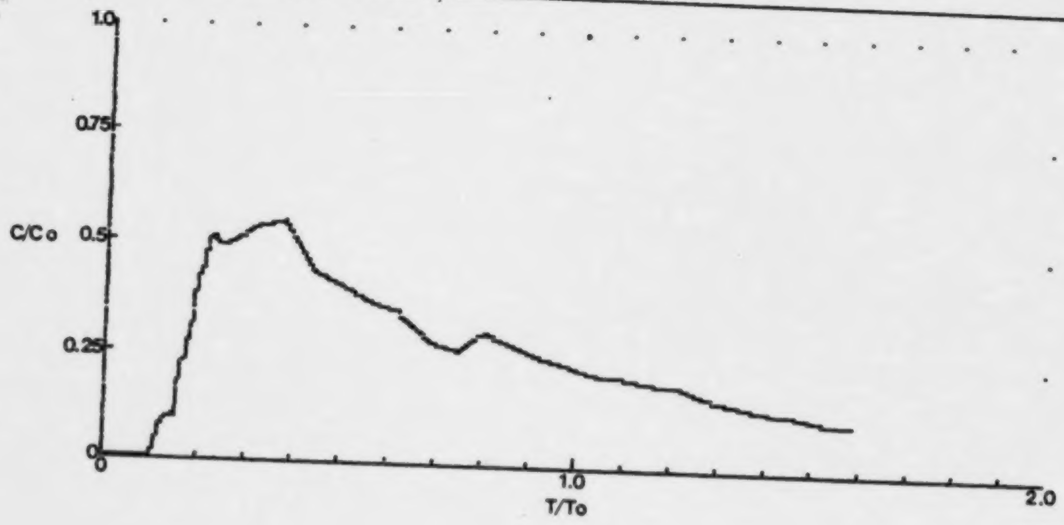


Figure 126. Results of the Point of Discharge Dispersion Test for Sand Lake Road secondary clarifier #1, 19 September 1979.

TABLE 17. PROCESS DATA ON THE SAND LAKE ROAD PLANT, 19 SEPTEMBER 1979

MLTSS	4430 mg/l

Settleometer test

Time (min)	Settled Sludge Volume	
0	1000	
5	260	
10	260	
15	260	
20	250	
25	200	
30	200	SVI = 45
40	190	
50	190	
60	190	

A Flow Pattern/Solids Distribution Test was conducted on 21 September 1979 with total plant flow split between two secondary clarifiers. Because flow split was uncertain, it was estimated that half the flow went to the test unit, #1. Total average plant effluent rate was 9.30 mgd (35,100 m^3/d), 61.9% of design effluent rate for the two clarifiers in operation at the time. This corresponds to a surface area overflow rate of 301 gpd/sq ft (12.26 $m^3/m^2 \cdot d$). Average underflow rate, uncertain, was estimated to be 3.06 mgd (11,580 m^3/d) for each clarifier.

The sampling procedure for the Flow Pattern/Solids Distribution Tests was unusual and lengthy. After starting continuous dye injection upstream of the clarifiers, samples were retrieved by riding the traveling bridge and pumping samples from five depths simultaneously as the bridge passed previously marked locations. The first flow pattern sample set was started at station 1, 7 min after starting the dye injection pump (t_o+7). This set was completed 10 min later, at station 5. The resulting flow pattern is illustrated in Figure 128. Similarly, the second set of samples was retrieved during the slower ride back toward the inlet end of the tank, during the sludge pickup phase, from t_o+17 to t_o+43. (The final sample in this set, at t_o+43, was on the last leg of the trip, toward the weirs.) This pattern is shown in Figure 129. The third set, illustrated in Figure 130, was sampled from t_o+43 to t_o+53.

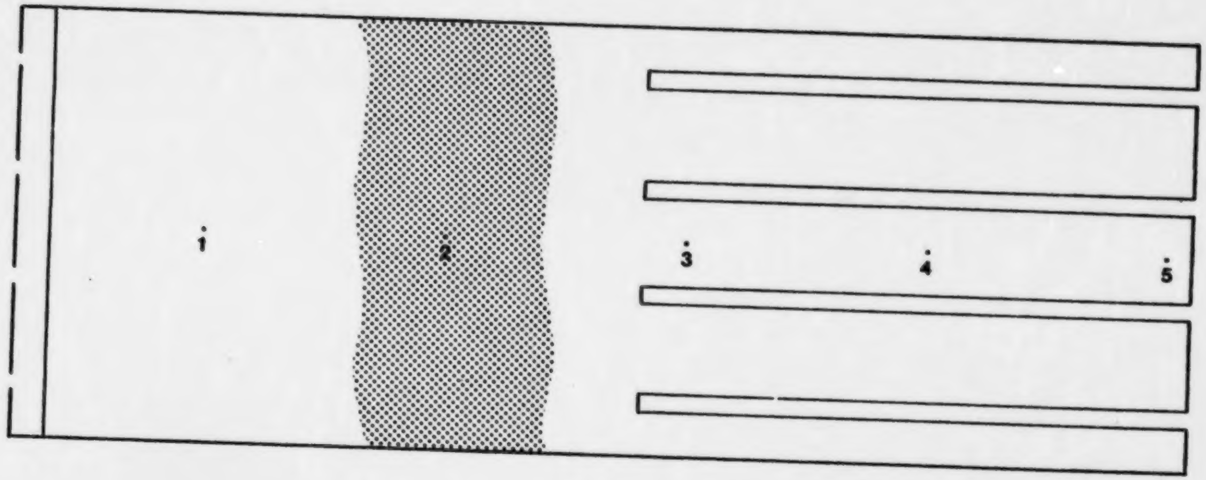


Figure 127. Plan view of the Sand Lake Road plant's secondary clarifier #1 showing a region, shaded, in which dye first appeared at the surface during the dispersion test, 19 September 1979.

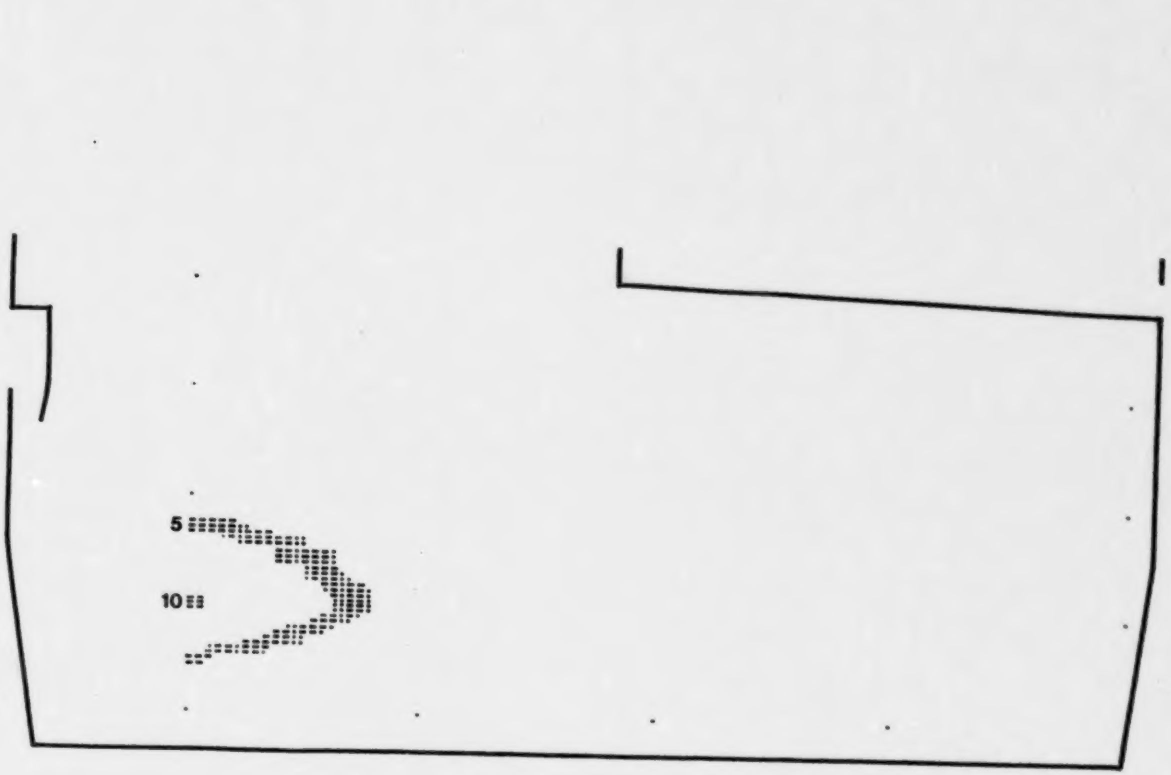


Figure 128. Longitudinal distribution of the dye concentration in Sand Lake Road secondary clarifier #1, 7-17 min after the start of continuous dye injection, 21 September 1979.

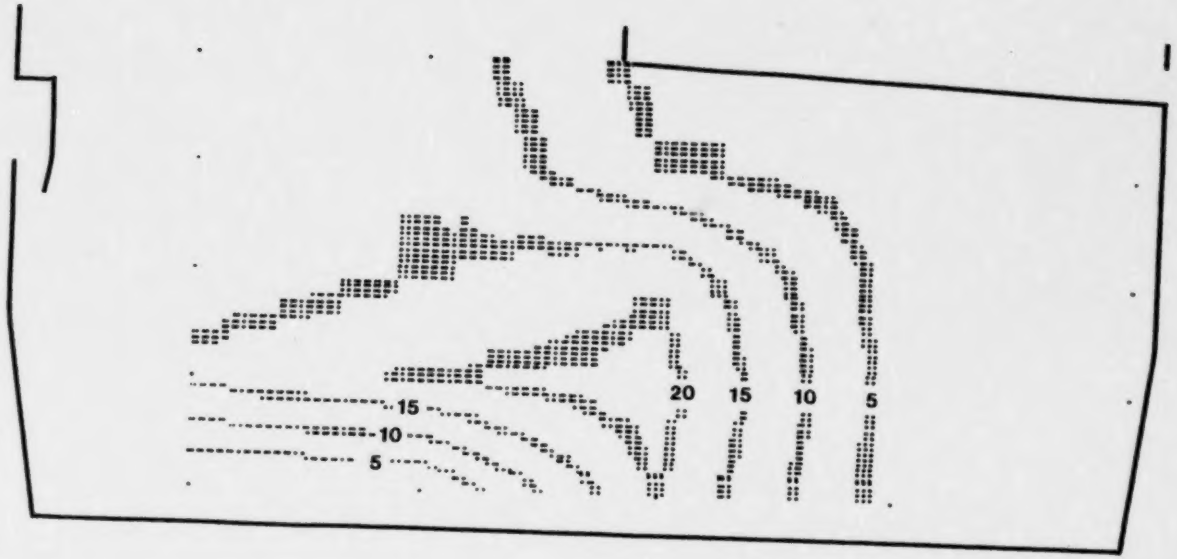


Figure 129. Longitudinal distribution of the dye concentration in Sand Lake Road secondary clarifier #1, 17-43 min after the start of continuous dye injection, 21 September 1979.

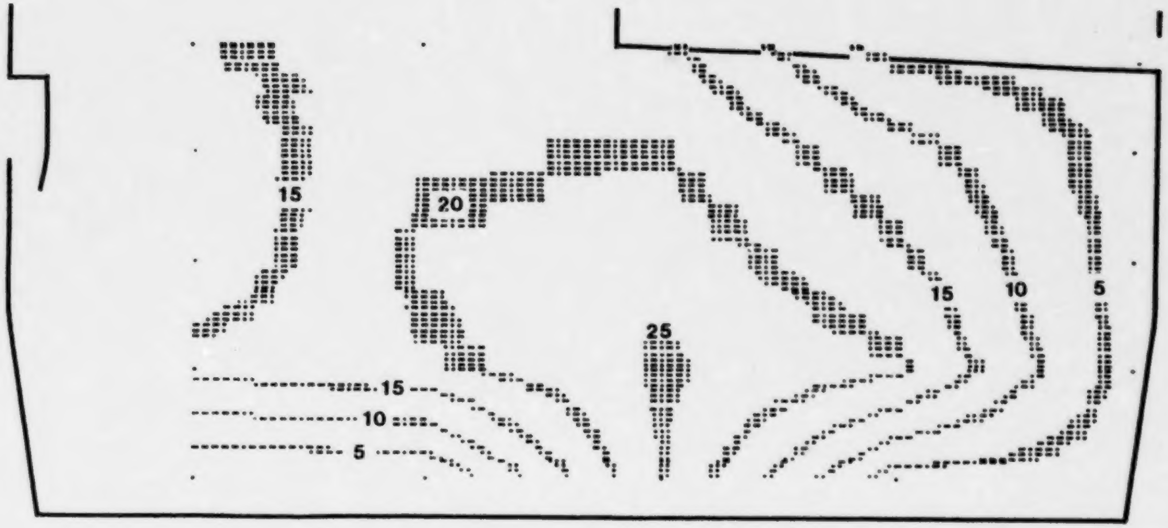


Figure 130. Longitudinal distribution of the dye concentration in Sand Lake Road secondary clarifier #1, 43-53 min after the start of continuous dye injection, 21 September 1979.

The longitudinal distribution of the square-root of total suspended solids, from sampling run #1, is presented in Figure 131. Note that the contours in the lower right-hand corner are believed to have resulted from a sampling error; the lowest sampling hose struck the 45 degree wedge-shaped tank fillet at this point, stirring up solids which had settled on the fillet. The same data which were contoured in Figure 131 were also used to contour the lower-concentration solids, from 10-30 mg/l, Figure 132. In this illustration, the values were not square-rooted. Contours greater than 30 mg/l were omitted for clarity. As before, the three contours in the lower right-hand corner are probably in error.

Laboratory data for the day of the low flow rate Flow Pattern/Solids Distribution Test is presented in Table 18.

A high flow rate Flow Pattern/Solids Distribution Test was conducted on 20 September 1979 with total plant flow passing through clarifier #1. Average effluent rate was 9.97 mgd (37,720 m^3/d). This is 133% of design effluent rate and corresponds to a surface area overflow rate of 645 gpd/sq ft (26.27 $m^3/m^2 \cdot d$). Underflow rate was estimated to be 3.28 mgd (12,400 m^3/d).

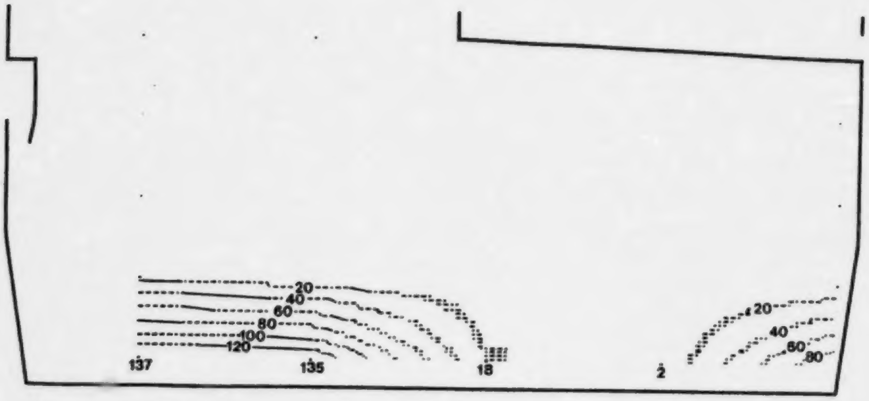


Figure 131. Longitudinal distribution of the square-root of total suspended solids in Sand Lake Road secondary clarifier #1, 21 September 1979.

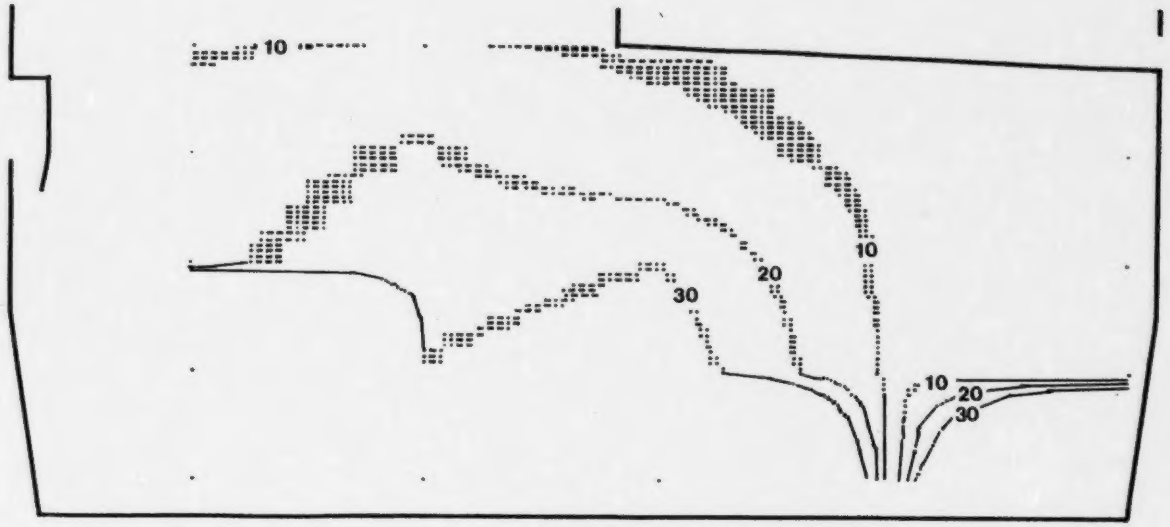


Figure 132. Longitudinal distribution of low concentration total suspended solids in Sand Lake Road secondary clarifier #1, 21 September 1979.

TABLE 18. PROCESS DATA FROM THE SAND LAKE ROAD PLANT, 21 SEPTEMBER 1979

MLTSS	4190 mg/l
Effluent TSS (grab) @ 1100	7 mg/l
Effluent TSS (grab) @ 1400	1 mg/l

Settleometer test

Time (min)	Settled Sludge Volume	
0	1000	
5	320	
10	260	
15	240	
20	230	
25	230	
30	220	SVI = 53
40	220	
50	210	
60	210	

The sampling procedure was similar to that used for the Flow Pattern/Solids Distribution Test just presented. The first sample series started at station 1 at t_o+7 and ended at station 5 at t_o+18. This pattern is shown in Figure 133. The second series began at station 5 at t_o+18 and ended at station 1 at t_o+39. The results of this run are presented in Figure 134. These were the only two sampling runs for this test.

The longitudinal distribution of the square-root of total suspended solids, from sampling run #1, is shown in Figure 135. The same solids data were also used to contour the lower concentration solids, from 10-30 mg/l, Figure 136. The data in Figure 136 were not square-rooted and contours greater than 30 mg/l were omitted for clarity.

Laboratory data for the day of the high flow rate Flow Pattern/Solids Distribution Test are shown in Table 19.

Discussion of Flow Pattern and Dispersion Results--

Median Retention time with respect to T_o, the theoretical maximum time based on influent rate, was 101.4/166.2 = 61%. In light of the differences in pre-modification flow patterns between the Sand Lake Road and Holly Hill clarifiers, it is surprising that the result of the Multi-Point Dispersion Test at Holly Hill produced a similar ratio, 52.7/94.5 = 56%.

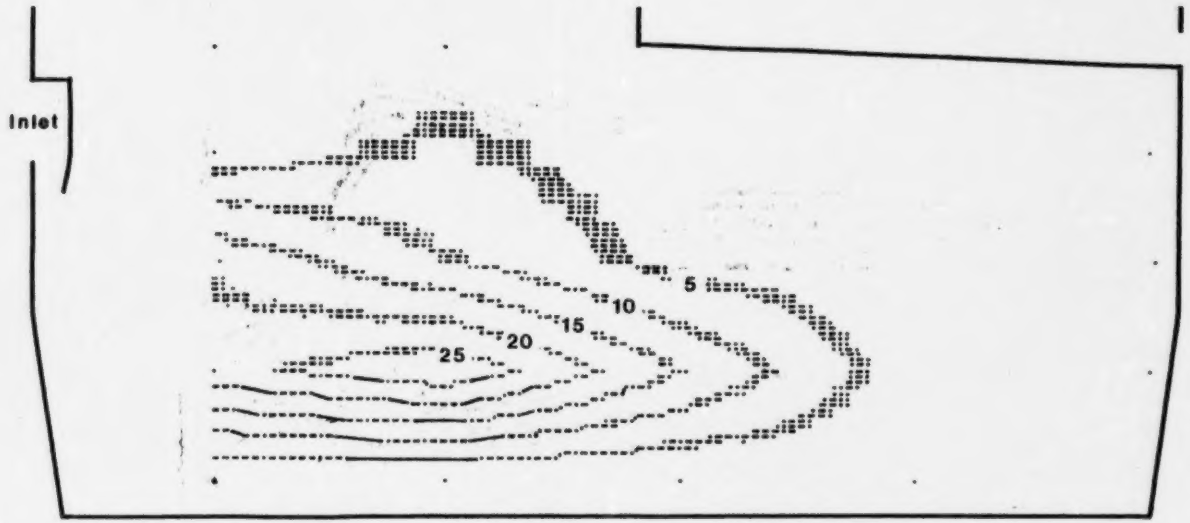


Figure 133. Longitudinal distribution of the dye concentration in Sand Lake Road secondary clarifier #1, 7-18 min after the start of continuous dye injection, 20 September 1979.

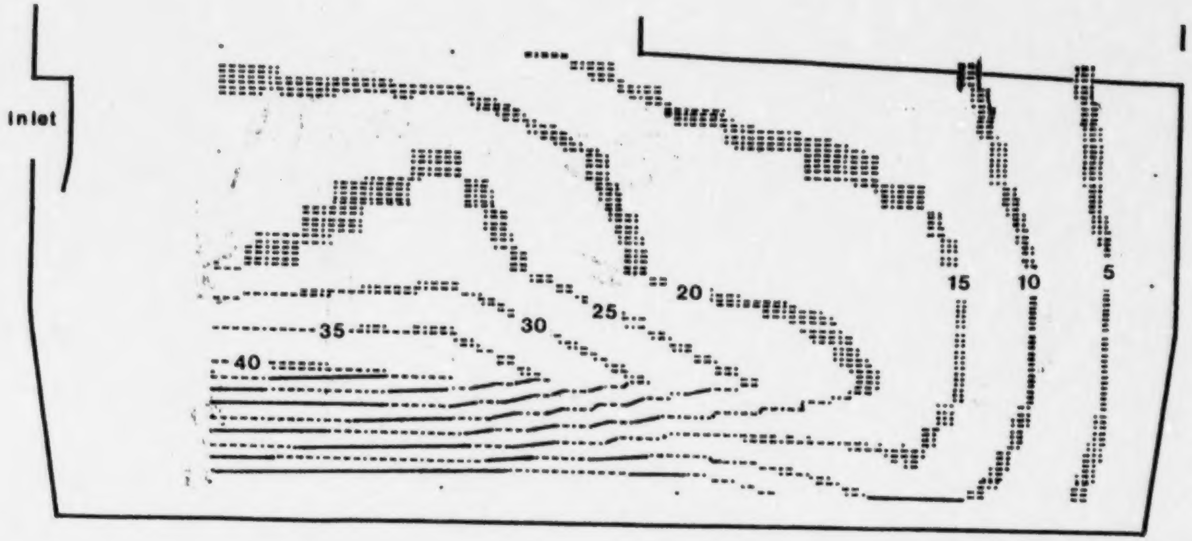


Figure 134. Longitudinal distribution of the dye concentration in Sand Lake Road secondary clarifier #1, 18-39 min after the start of continuous dye injection, 20 September 1979.

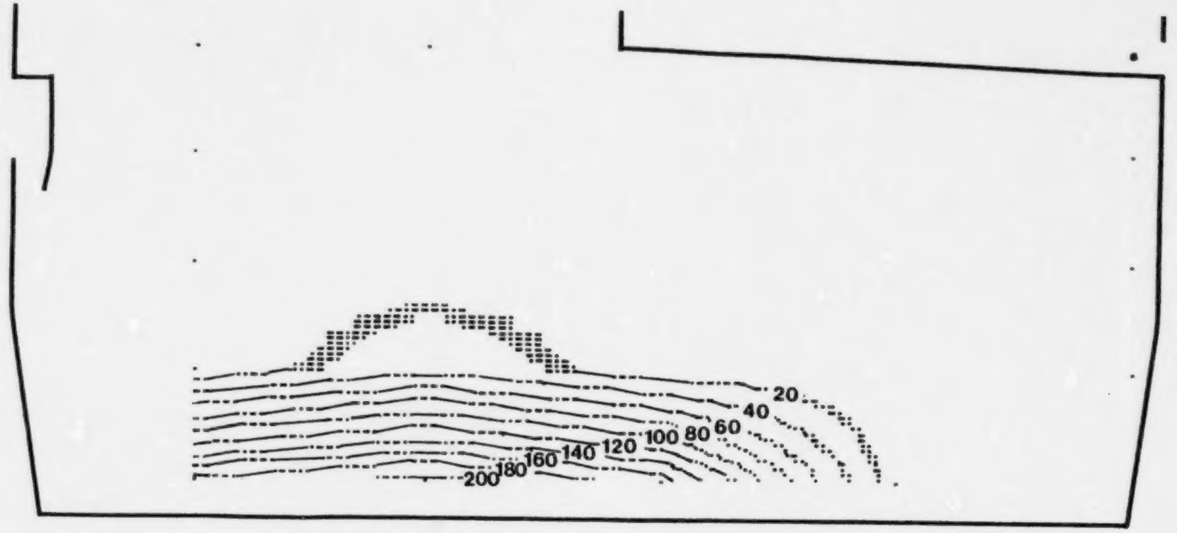


Figure 135. Longitudinal distribution of the square-root of total suspended solids in Sand Lake Road secondary clarifier #1, 21 September 1979.

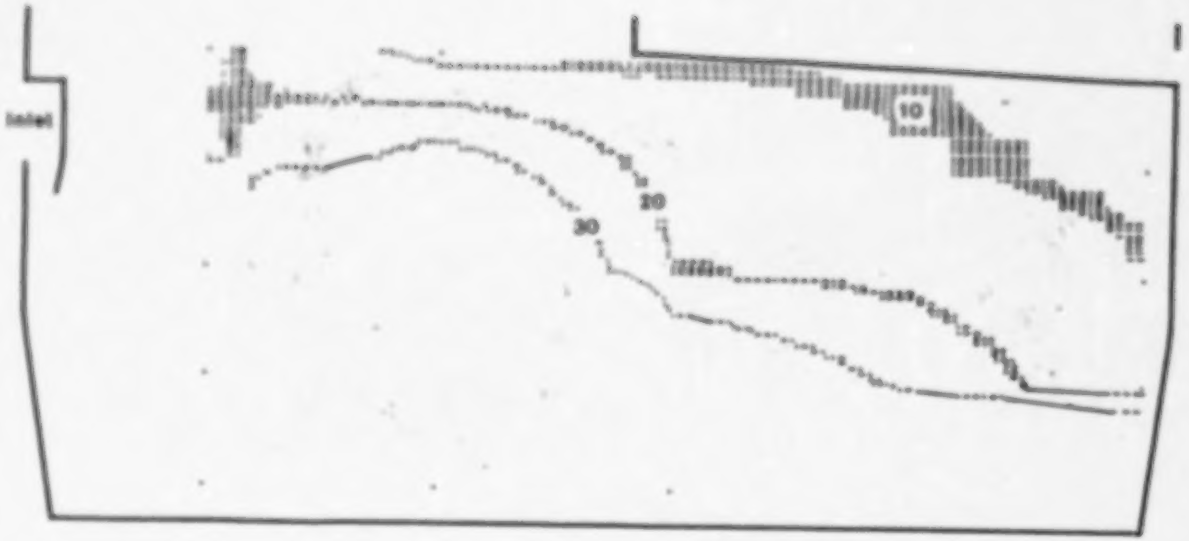


Figure 136. Longitudinal distribution of low concentration total suspended solids in Sand Lake Road secondary clarifier #1, 21 September 1979.

TABLE 19. PROCESS DATA FROM THE SAND LAKE ROAD PLANT, 20 SEPTEMBER 1979

MLTSS	3545 mg/l
Effluent TSS (grab) @ 1100	7 mg/l
Effluent TSS (grab) @ 1400	9 mg/l

Settleometer test

Time (min)	Settled Sludge Volume	
0	1000	
5	230	
10	220	
15	200	
20	190	
25	190	
30	180	SVI = 51
40	170	
50	170	
60	170	

The flow patterns defined at the Sand Lake Road plant were unique in the investigator's experiences. Although Figure 128 only suggests that the commonly observed top-of-blanket horizontal flow is developing, Figure 129 gives an entirely new picture; upflow is occurring in the inlet half of the tank, as shown by the uppermost 5,10 and 15 ppb contours. Further, the vertical stance of the right-hand and lower parts of these same contours suggest a condition which approximates plug-flow. Plug-flow, a condition in which flow progrssses at uniform velocity in any given cross-section from inlet to outlet region, is one theoretically ideal model. (Another ideal model is uniform upflow over the entire surface. The theoretical settling models will be discussed in Section 7 of this report.) The third flow pattern in the series, Figure 130, is more difficult to interpret, but near-ideal throughflow conditions appear to have been achieved in the 5, 10 and 15 ppb contours on the right-hand side of the illustration.

Figures 127 and 131 offer clues to the reason for the unusual throughflow patterns. In Figure 131, a wedge of compacted solids with a maximum concentration of 18,831 mg/l was measured 1 ft (0.3 m) above the bottom of the tank. From the outgassing observed near station 2, Figure 127, it is believed that this sludge wedge is septic. Figure 132 shows that only low suspended solids concentrations reached the weir vicinity.

Figure 133 again shows the initial top-of-blanket flow pattern, but this time, upflow at station 2 is more clearly defined by the 5 ppb contour. Figure 134 presents a very clear picture of inlet-region vertical mixing followed by the development of plug-flow at the right-hand or overflow weir end of the illustration. Figure 135 gives us more information; the same high concentration solids wedge is visible, with a maximum concentration of 42,000 mg/l at station 2, but the 20 contour shows upward movement of solids at concentrations of at least 400 mg/l at this station. The lower concentration suspended solids distribution, Figure 136, suggests a nearly ideal settling condition. Only low solids concentrations, less than 10 mg/l, approach the overflow weirs.

These data offer the clearest evidence to date in this study that good vertical distribution of the incoming mixed liquor is desirable as suggested by settling theory[6] and design standards[7]. As has been demonstrated in earlier sections of this report, ideal throughflow conditions are seldom achieved. The only other exception presented was the peripheral feed, peripheral overflow unit at the Oakland, CA, EBMUD main plant where, under conditions of low blanket and design flow rate, entire surface area upflow was approximated.

The resident wedge of septic sludge in clarifier #1 of the Sand Lake Road plant would normally be considered an undesirable condition. However, the principal investigator believes that any change in sludge return practice which removes this sludge will also remove the rising-bubble condition which seems to enhance vertical mixing in the inlet region, which apparently results in a nearly ideal throughflow regime and good distribution of low concentration total suspended solids.

Plant Flows--

Although raw sewage flow to the Sand Lake Road plant is relatively steady, with a smooth diurnal variation normal for a plant of this size, the in-plant flow variability is of interest. This discussion is presented as evidence of the existence of plant seiche and of the velocity of small amplitude wave propagation. Both of these topics will be discussed in more detail in Section 7.

As previously described, each of the four secondary clarifiers has a traveling bridge with 8 air lift pumps for sludge return. Each unit returns sludge for 24 min while traveling from the outlet to the inlet end of the clarifier. During the 12 min travel time back to the outlet end, the air lift pumps do not operate. For each clarifier, startup of the air lift pumps results in a rapid decrease in overflow rate, as will be shown. Since the bridges are not synchronized with each other, total plant effluent rate is highly variable despite the steadiness of raw sewage feed to the plant. This variability causes an operating problem in chlorine feed rate, downstream of the secondaries.

All plant flow was diverted to clarifier #1 on 19 September 1979 for the Point of Discharge Dispersion Test, already presented. While conducting this test, the investigator also recorded plant effluent rate several times per minute in the plant's control room while simultaneously recording radio reports of air-lift pump on-off events transmitted by an assistant at the clarifier. The result of this flow/sludge return test is illustrated in Figure 137. The investigator interprets Figure 137 as follows:

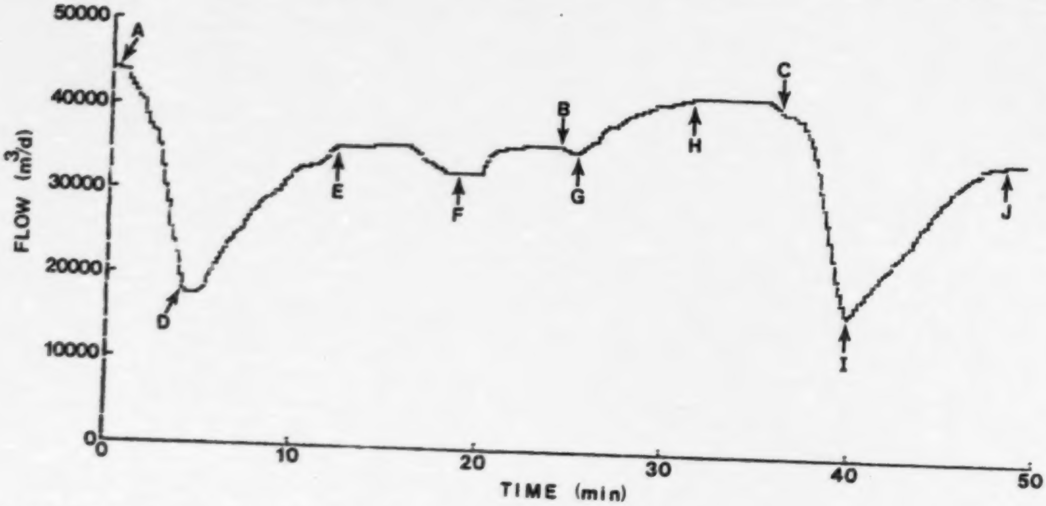


Figure 137. Overflow of Sand Lake Road secondary clarifier #1 showing just over one on-off cycle of traveling bridge air lift pumps, 19 September 1979.

At point A, Figure 137, the return sludge air lift began. After a brief delay, effluent rate began a sharp decline. (Approximately 32 seconds of this delay is accounted for by the time of travel of effluent from the clarifier #1 discharge channel to the flowmeter.) In just over 4 min, flow had decreased from a peak value of 11.5 mgd (43,600 m^3/d) to 4.60 mgd (17,410 m^3/d) at point D. During this 4 min, the return sludge wave was traveling down 200 ft (60 m) of narrow channel atop the clarifier itself, through the common return sludge channel, through aeration, back to the overflow weirs and the discharge channel to the flow sensor. Between D and E, the return sludge wave gradually reached a semi-equilibrium overflow rate. Between E and F and F and G, there appear to be two cycles of 6½ minute period which may represent natural whole plant hydraulic system seiche. At B, the return sludge airlift was turned off. Within two minutes, the flow began to increase to a new equilibrium value, 11.096 mgd (42,000 m^3/d) at H. At C, the airlift was again started and the cycle began anew. Points C and I are similar to A and D, the beginning of a new cycle.

The flow record of Figure 137 was used to estimate the average return sludge flow rate by noting the average difference in flows at points A and D and points C and I and assuming that this difference was the return sludge flow rate during air-lift operation, 24 of each 36 minutes. Because the return sludge wave had traveled throughout the plant in 4 min, returning to the point of discharge at point D on the record, actual estimates for return sludge flow rate may be low; point D may have reached a lower flow value had the sludge wave not reached the point of discharge so soon.

Similar periodic variations in the plant discharge can be seen in the circular chart records for 19,20 and 21 September 1979, the field study days of this test series. The charts could not be clearly reproduced for this report. Because effluent quality was consistently good during this study, there is no evidence that the flow variability was detrimental to clarifier performance. Although overflow and underflow rates were obviously variable, and the points of fluid removal are continuously changing, mixed liquor feed rate to the clarifiers may have been relatively steady.

Stamford, Connecticut

Facility Description--

Numerous hydraulic studies were conducted on two secondary clarifiers at the Stamford Water Pollution Control Facility. The work was conducted in two phases, the first of which included an evaluation of a peripheral baffle in clarifier #1. The second phase concentrated on identifying physical factors affecting solids transport in clarifier #2. All of the work for this phase was not completed.

Stamford's municipal wastewater treatment plant utilizes an air activated sludge process for primarily domestic wastewater. A process schematic is shown as Figure 138.

The plant has two identical 130 ft (40 m) diameter center feed, peripheral overflow secondary clarifiers, shown as Figures 139 and 140. Sidewater depth is 13 ft (4.0 m). A bottom slope of 1:12 gives a maximum center depth of 18.4 ft (5.61 m). Design effluent rate for each unit is 10 mgd (3,800 m3/d). The inlet feedwells have solid walls and are 18 ft (5.5 m) in diameter with a submerged depth of 5.8 ft (1.76 m). Inside the feedwells, there are four mixed liquor inlet ports, positioned at 90 degrees to each other, on a 4 ft (1.2 m) diameter center column. One of these ports is in the direction of the access bridge on both clarifiers. Sludge is removed by 10 riser pipes distributed along the scraper arms. Riser pipe rotation rate is 1 revolution per 35.6 min. Figure 141 is a view inside the feedwell structure, showing the general relation between one of the 4 inlet ports, the riser pipes, and the feedwell (background). Scum rakes and sumps are provided. The clarifiers have weirs at the periphery of the tanks only.

During the phase 1 work in which the new peripheral baffle was evaluated, the electromagnetic flowmeters for return and waste sludge measurement from each clarifier were not operational. Neither influent nor overflow rate measurement instrumentation was available. The total plant flow meter was unreliable. For the comparative study, approximate flow balance between secondaries was achieved during peak flow hours by throttling one gate valve at the splitter box, by cut-and-try, using simultaneous dye dilution flow measurement on both secondary clarifiers. For the comparative evaluation, effluent total suspended solids were composited only during weekdays, from 0900 to 1500, the peak flow hours.

Following the baffle evaluation, several additions and improvements were added to the plant's instrumentation and controls to allow a more detailed hydraulic analysis of solids transport phenomena in unmodified secondary clarifier #2.

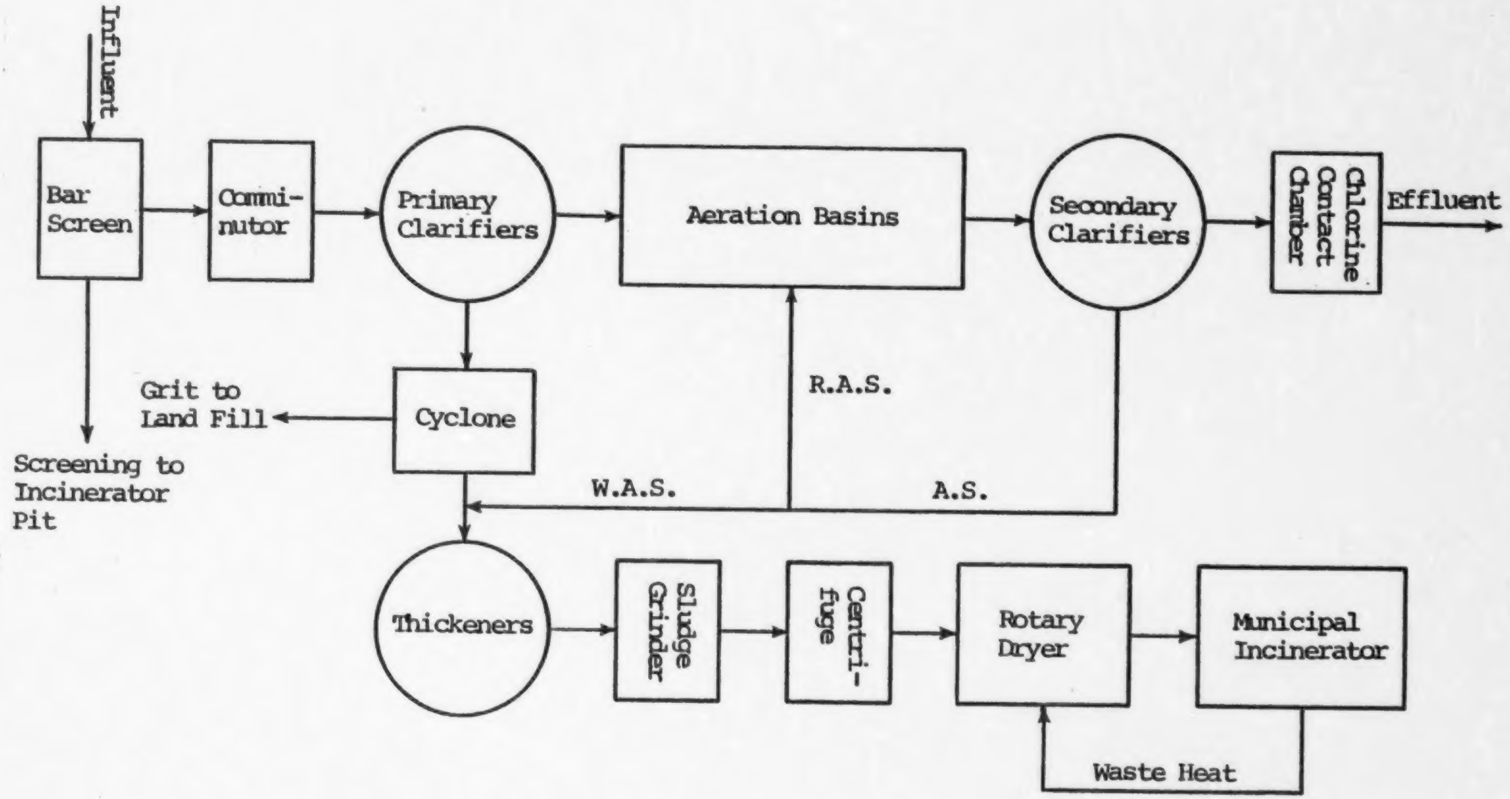
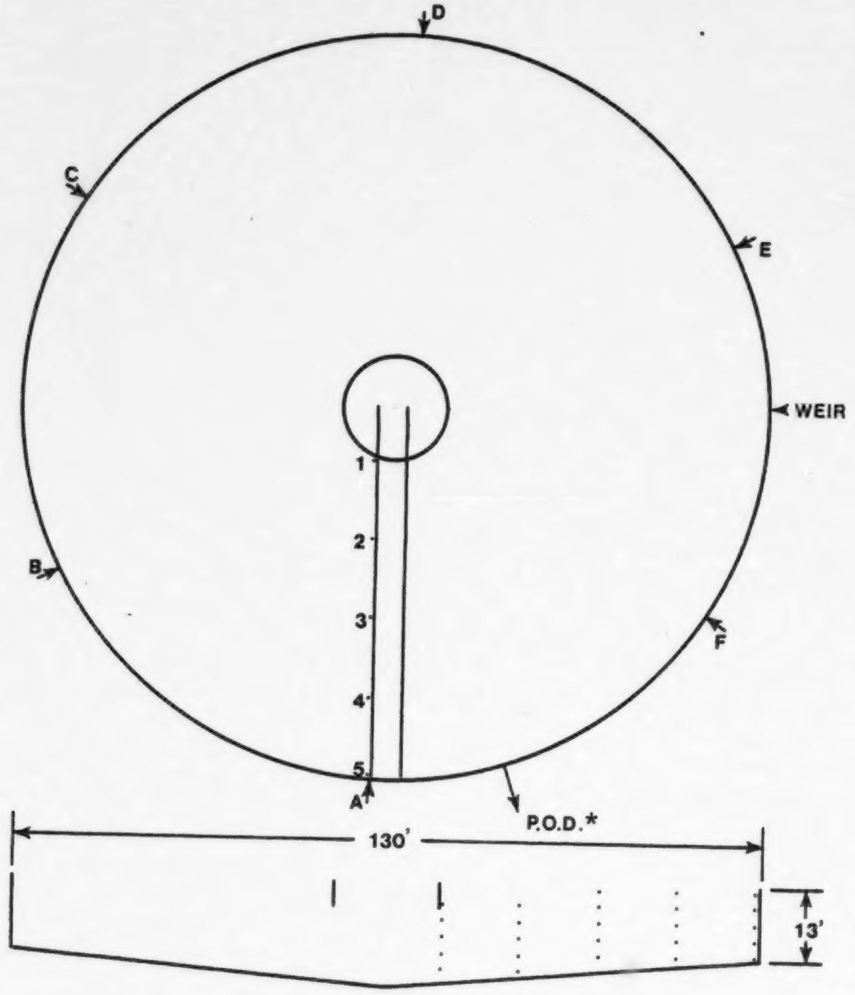

Influent
Bar Screen
Commi-nutor
Primary Clarifiers
Aeration Basins
Secondary Clarifiers
Chlorine Contact Chamber
Effluent
Grit to Land Fill
Cyclone
R.A.S.
Screening to Incinerator Pit
W.A.S.
A.S.
Thickeners
Sludge Grinder
Centri-fuge
Rotary Dryer
Municipal Incinerator
Waste Heat

Figure 138. Process schematic for the Stamford, CT water pollution control facility.



*Point of Discharge

Figure 139. Plan and elevation of the Stamford, CT secondary clarifier #1.

1. The plant's electromagnetic flowmeters for return and waste sludge were repaired and calibrated.

2. Level guage flowmeters were installed on both secondaries. Motorized controllers were installed on the gate valves which feed mixed liquor to each secondary from the splitter box. A servo system was constructed and installed to control the mixed liquor feed rate and maintain a selectable, constant overflow rate for secondary clarifier #2, with the new level guage on the surface of #2 secondary as the servo controlling sensor.

3. A recording temperature guage was installed in the mixed liquor inlet pipe on secondary #2. A second temperature

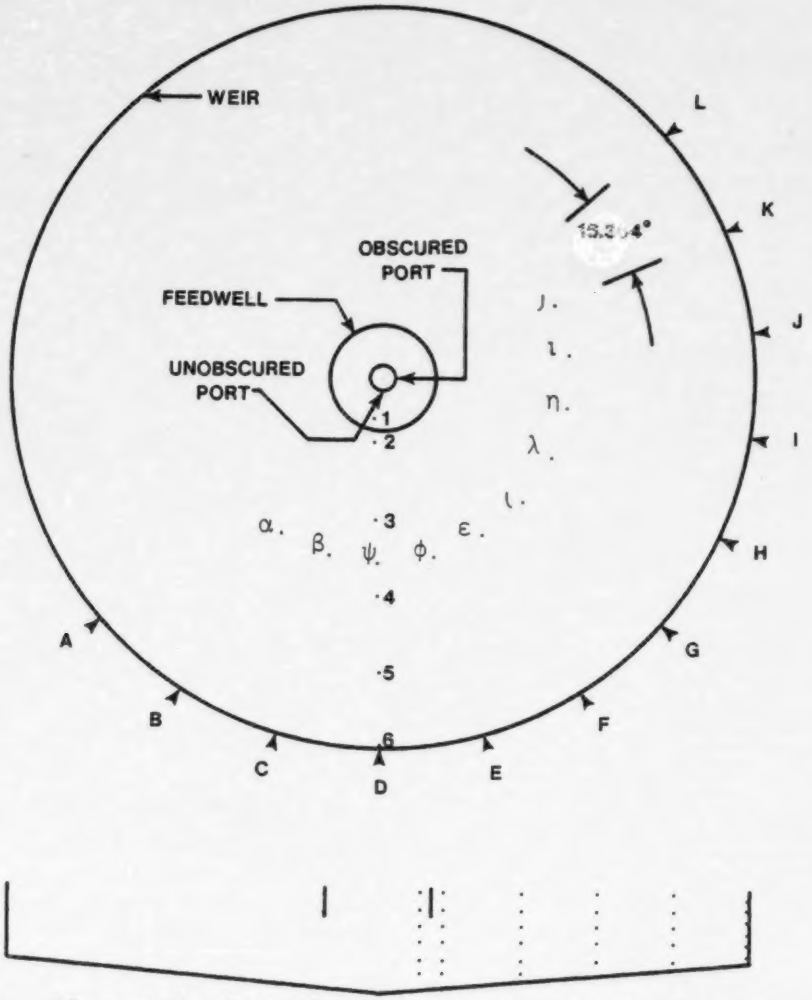

WEIR
L
K
15.3[illegible]4°
OBSCURED PORT
FEEDWELL
UNOBSCURED PORT
J
j.
ι.
η.
I
λ.
ι.
1
2
3
α.
β.
ψ.
ϕ.
ε.
H
4
A
G
5
B
F
6
C
D
E

Figure 140. Plan and elevation of the Stamford, CT secondary clarifier #2.

sensor was installed just beneath the #2 clarifier overflow weir. The output of this second temperature sensor was electronically coupled to the output of the inlet sensor to record the difference between influent and overflow temperatures to an accuracy of 0.02°C.

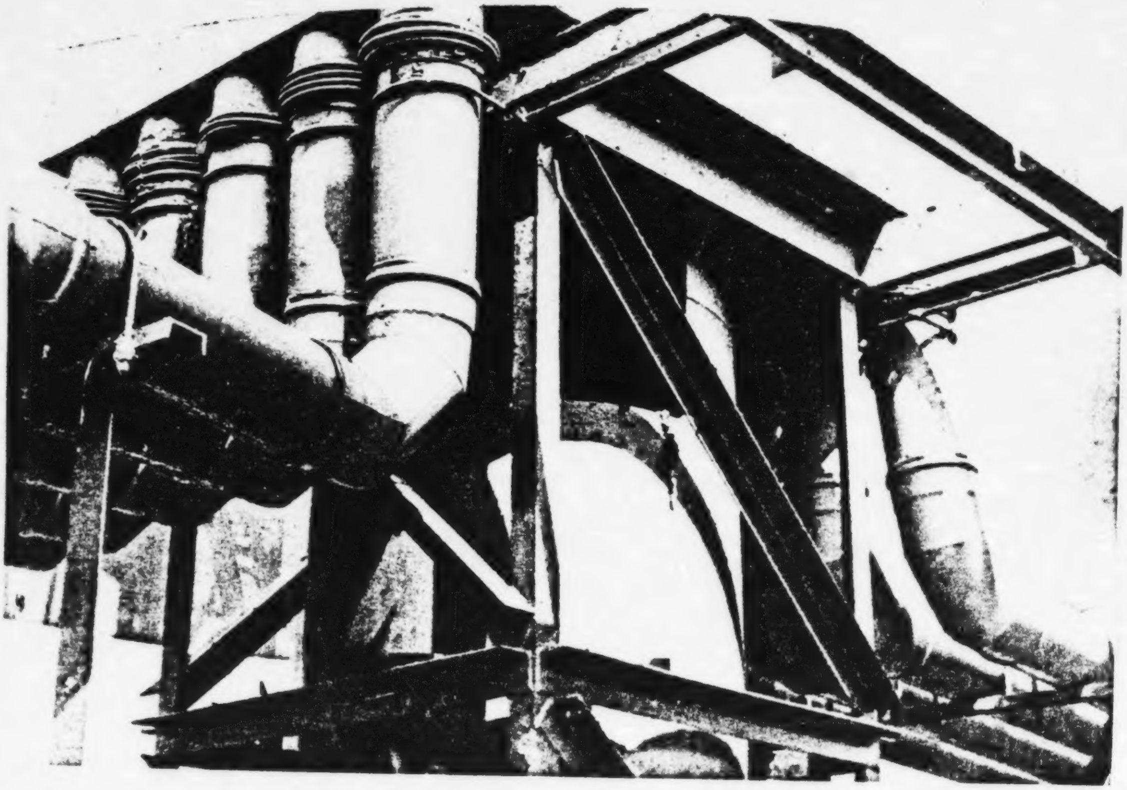


Figure 141. A view, from below, of one of the Stamford clarifier's feedwells. The rectangular inlet port (one of four), top center, is stationary. The riser pipes, feedwell and other structural members rotate once every 35.6 min.

Initial Hydraulic Tests, Clarifier #1--

A Multi-Point Dispersion Test was conducted on 6 August 1979. Average effluent rate of the test clarifier during the test was 9.390 mgd (35,540 m^3/d). This is equivalent to a surface area overflow rate of 707 gpd/sq ft (28.80 $m^3/m^2 \cdot d$). Underflow rate was not known, but was estimated to be 3.3 mgd (12,000 m^3/d). The sludge blanket was at a depth of 13.8 ft (4.21 m), by optical sensor.

After release of 1000 ml of Rhodamine WT just downstream of the aeration basins, samples were retrieved at 6 peripheral stations at 5 min intervals for 1 hour and thereafter at less frequent intervals for a total of 267 min.

Physical data pertinent to the dispersion test are presented in Table 20. The 6 Multi-Point Dispersion plots are shown in Figures 142 through 147. These plots are presented with an expanded time scale to give better detail of the peak characteristics. In all cases, the "tails" of the curves continued a smooth decline. Additionally, an "average dispersion curve" was constructed by averaging the data from the 6 sampling points. This constructed curve is shown in Figure 148.

TABLE 20. PHYSICAL DATA PERTINENT TO THE DISPERSION TEST ON STAMFORD SECONDARY CLARIFIER #1, 6 AUGUST 1979

Background fluorescence = 0.5 ppb
Tank volume = 1,470,000 gal
Average effluent rate during test = 9.39 mgd
Estimated underflow rate during test = 3.3 mgd
Retention time based on influent rate, T_O = 167.5 min
500 ml of dye added to test clarifier only
Flash mix fluorescence, C_O = 89.9 ppb

Weir Station	Relative Dye Mass Overflowing Weir Station	Median Retention Time for This Test (min)
A	0.427	113.3
B	0.466	112.3
C	0.536	100.5
D	0.460	111.3
E	0.411	121.8
F	0.436	119.6

Process related samples were retrieved twice during the dispersion test. The results of laboratory tests on these samples are shown in Table 21.

It is useful to note that the period between passage of one or the other riser pipe arms is 17.8 min. This corresponds to 17.8/167.5 = 0.106 T/T_O units. This is roughly the period between peaks which are most prominent in Figures 142 through 144, stations A, B and C.

A Flow Pattern/Solids Distribution Test was conducted on 7 August 1979. Effluent rate from clarifier #1 was 8.34 mgd (31,600 m^3/d). This is equivalent to a surface area overflow rate of 628 gpd/sq ft (25.58 $m^3/m^2 \cdot d$). Underflow was estimated to be 3.3 mgd (12,000 m^3/d). The sludge blanket was measured by optical sensor at a depth of 13.8 ft (4.21 m). Both secondary clarifiers were in operation during the test.

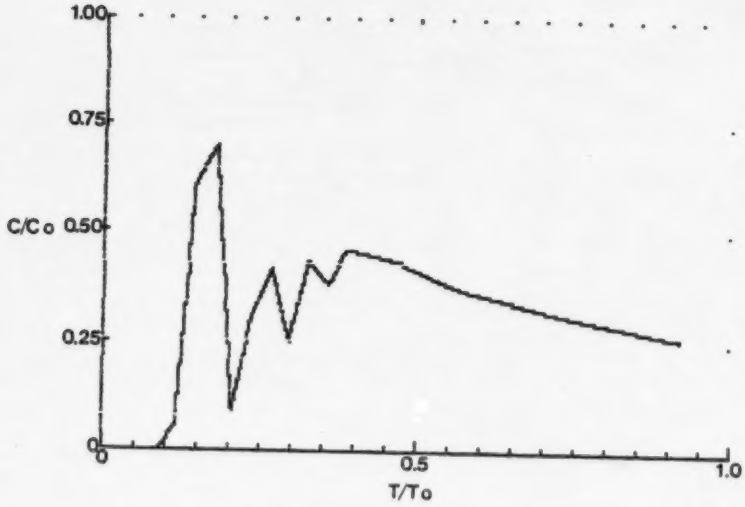


Figure 142. Results of the Multi-Point Dispersion Test of Stamford secondary clarifier #1, weir station A, 6 August 1979.

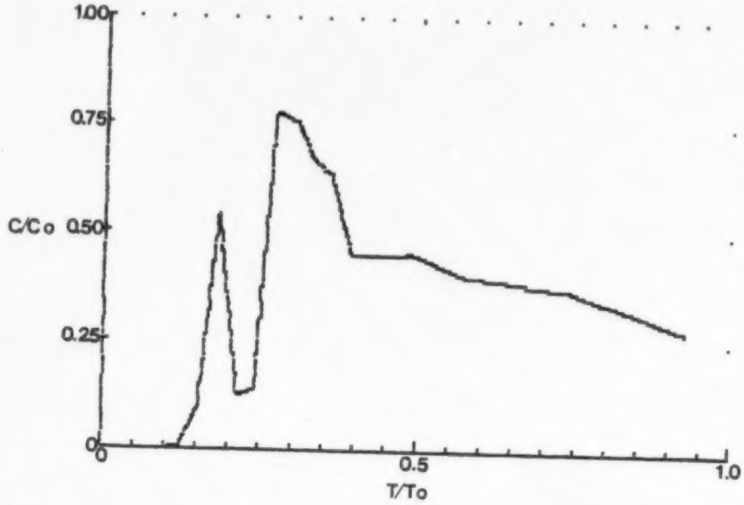


Figure 143. Results of the Multi-Point Dispersion Test of Stamford secondary clarifier #1, weir station B, 6 August 1979.

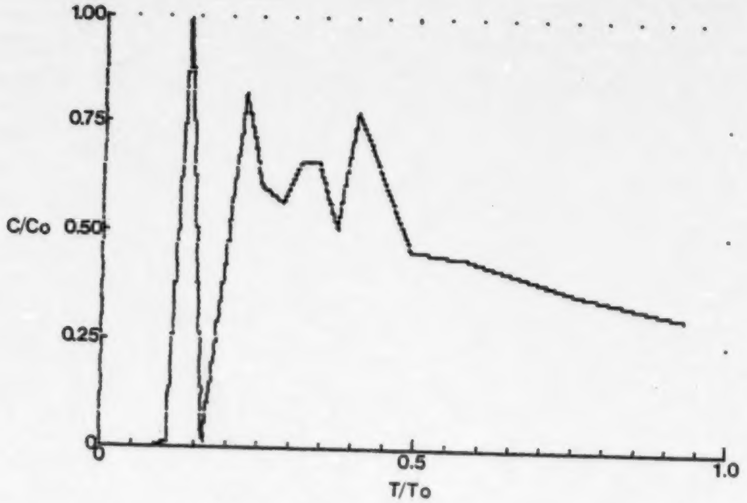


Figure 144. Results of the Multi-Point Dispersion Test of Stamford secondary clarifier #1, weir station C, 6 August 1979.

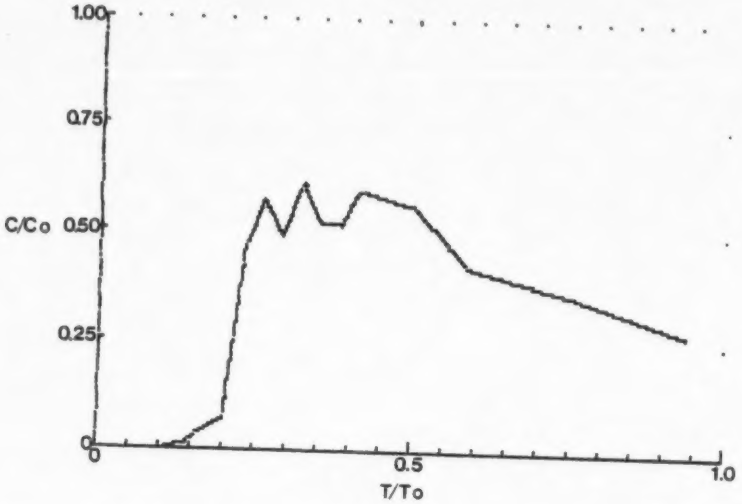


Figure 145. Results of the Multi-Point Dispersion Test of Stamford secondary clarifier #1, weir station D, 6 August 1979.

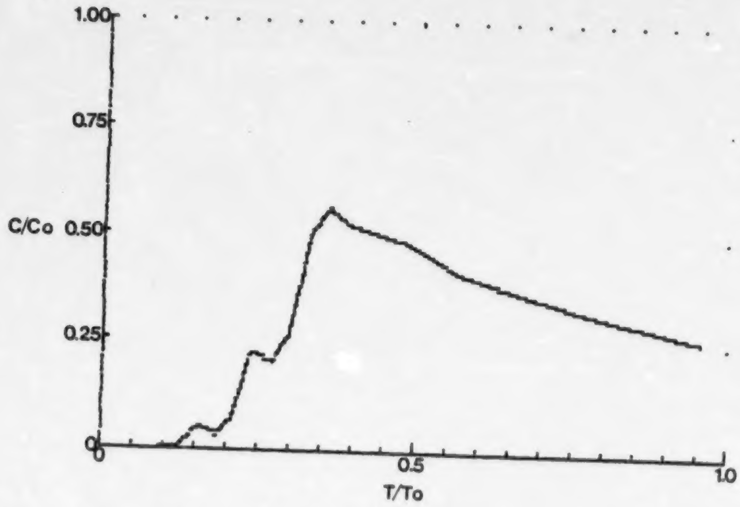


Figure 146. Results of the Multi-Point Dispersion Test of Stamford secondary clarifier #1, weir station E, 6 August 1979.

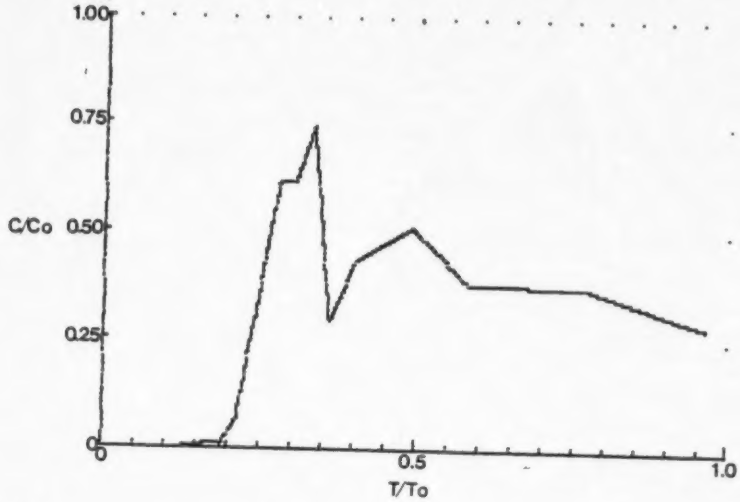


Figure 147. Results of the Multi-Point Dispersion Test of Stamford secondary clarifier #1, weir station F, 6 August 1979.

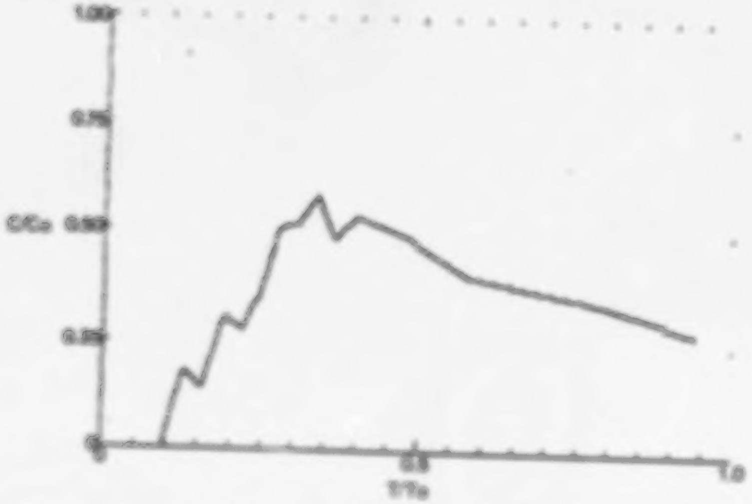


Figure 148. Average result of the Multi-Point Dispersion Test of Stamford secondary clarifier #1, 6 August 1979.

Dye injection, at a rate of 10 ml/min, was started at 1248, just downstream of the aeration basins. Three sampling runs were made at intervals of 17.8 min, just after one or the other header arms had passed the access bridge, from which samples were taken. The flow pattern results of the sampling runs are presented in Figures 149 through 151. The radial distribution of total suspended solids is illustrated in Figure 152. Note that in this case, the solids distribution data were contoured directly, not as square-root, because the data seemed clearer in this format. The upper right-hand sampling point was not included in the dye or solids contour. From lack of foresight, this sampling point was located adjacent to, and just inside the 18 inch (0.5 m) deep scum baffle, at a depth of 1 ft (0.3 m). Data are not considered reliable at the sampling point.

Laboratory data for the day of the Flow Pattern/Solids Distribution Test are presented in Table 22.

The contours in Figure 149 indicate a horizontal flow layer of moderate thickness at a depth of 12-13 ft (3.7-4.0 m). This flow layer turns upward at the peripheral wall. Figures 150 and 151 illustrate the progression of dye into a backeddy region, nearer the center of the tank. Figure 152 clearly shows that the lower concentration solids move upward at the peripheral wall, following the major flow route defined by Figure 149.

It should be noted that the radial sampling section was later found not to be representative of all outward flow directions: the access bridge is in a direct line with one of the four inlet ports.

TABLE 21. PROCESS DATA ON THE TEST CLARIFIER, STAMFORD, CT, 6 AUGUST 1979

MLTSS @ 1235	2510 mg/l
Effluent TSS (grab) @ 1235	20 mg/l
TSS of settleometer test supernatant after 60 min	31 mg/l

Settleometer Test

Time (min)	Settled Sludge Volume (ml/l)	
5	360	
10	280	
15	240	
20	220	
30	200	SVI = 80
60	180	

MLTSS @ 1400	2350 mg/l
Effluent TSS (grab) @ 1400	31 mg/l
TSS of settleometer test supernatant after 60 min	33 mg/l

Settleometer Test

Time (min)	Settled Sludge Volume (ml/l)	
5	320	
10	260	
15	230	
20	210	
30	190	SVI = 81
60	180	

A Weir-Wall Solids Test was conducted on 8 August 1979. The effluent rate of clarifier #1 was 9.24 mgd (35,000 m^3/d). This is a surface area overflow rate of 697 gpd/sq ft (28.40 $m^3/m^2 \cdot d$). Underflow was estimated to be 3.3 mgd (12,000 m^3/d). The sludge blanket was at a depth of 13.7 ft (4.18 m) by optical sensor.

The test included a time-series of 19 samples at each of five depths, 1.00, 3.75, 6.50, 9.25 and 12.0 ft (0.305, 0.335, 1.981, 2.819 and 3.66 m). Sampling station #5 was used, at the weir end of the access bridge. It was later found that this station is in a direct line with one clarifier inlet port. Test results are presented in Figures 153 through 157. Pertinent process data for this test day are shown in Table 22. In viewing the figures, please note that data at the 1 ft (0.3 m) sampling depth are not considered to be representative. The sampling point was adjacent to, and just inside the relatively deep scum baffle.

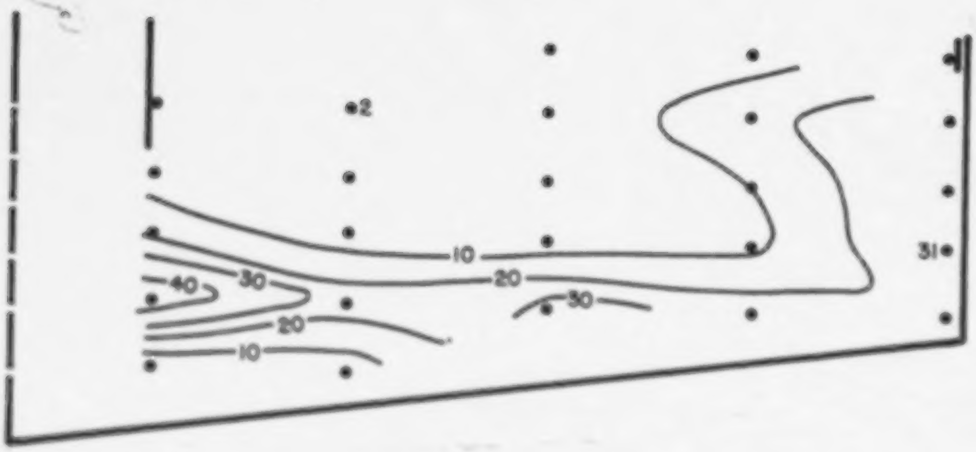


Figure 149. Radial distribution of the dye concentrations in Stamford secondary clarifier #1, 20 min after the start of continuous dye injection, 7 August 1979.

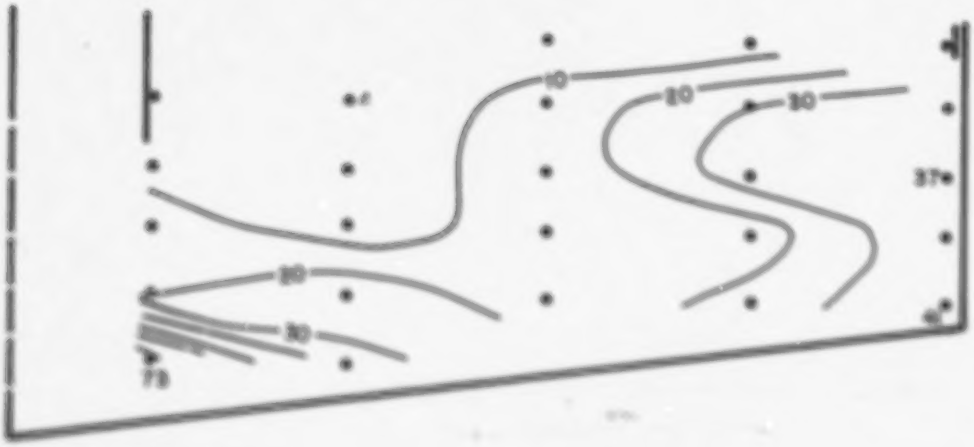


Figure 150. Radial distribution of the dye concentrations in Stamford secondary clarifier #1, 38 min after the start of continuous dye injection, 7 August 1979.

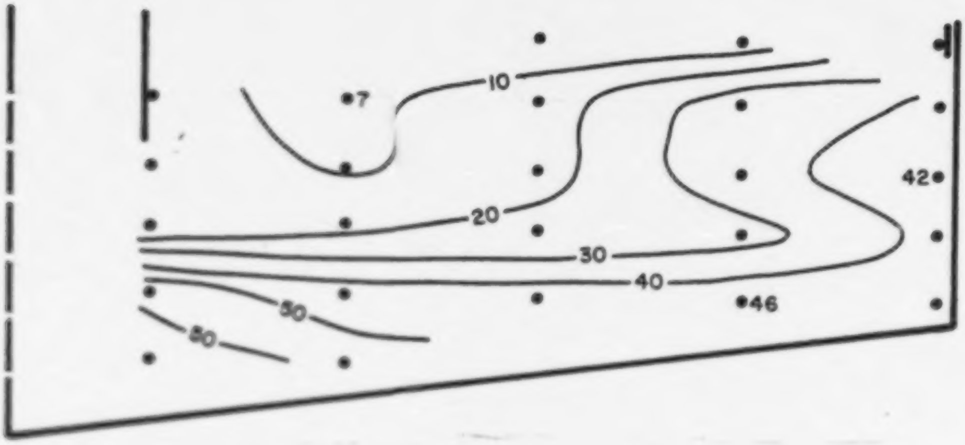


Figure 151. Radial distribution of the dye concentrations in Stamford secondary clarifier #1, 55 min after the start of continuous dye injection, 7 August 1979.

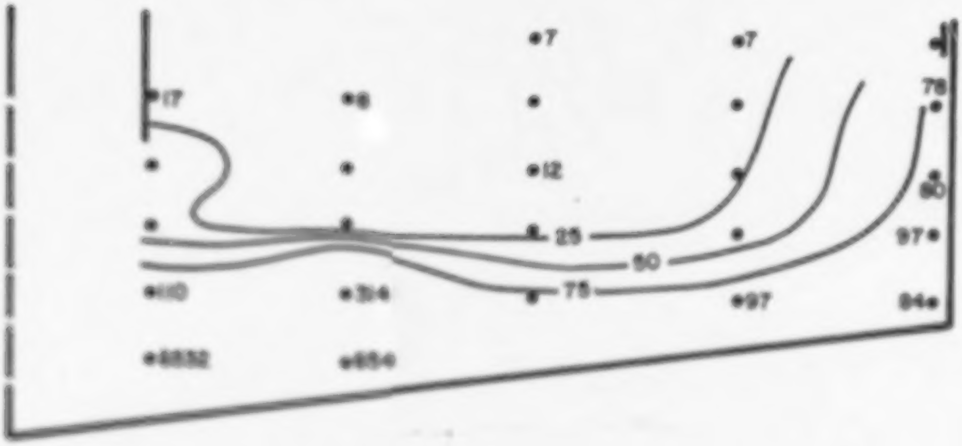


Figure 152. Radial distribution of total suspended solids in Stamford secondary clarifier #1, 7 August 1979. Note that contured values are not square-roots, as explained in the text.

TABLE 22. PROCESS DATA ON THE TEST CLARIFIER, STAMFORD, CT, 7 AUGUST 1979

MLTSS @ 1100	2470 mg/l
Effluent TSS (grab) @ 1100	20 mg/l
TSS of settleometer test supernatant after 60 min	31 mg/l

Settleometer Test

Time (min)	Settled Sludge Volume (ml/l)	
5	350	
10	260	
15	240	
20	220	
30	200	SVI = 81
60	190	

MLTSS @ 1400	2430 mg/l
Effluent TSS (grab) @ 1400	74 mg/l
TSS of settleometer test supernatant after 60 min	32 mg/l

Settleometer Test

Time (min)	Settled Sludge Volume (ml/l)	
5	350	
10	260	
15	230	
20	210	
30	200	SVI = 82
60	180	

The data in Figures 154 through 156 can be visually correlated with the 17.8 min period of sludge header passage. The information in Figure 154 is considered most significant because high solids concentrations periodically occur 3.75 ft (1.143 m) from the overflow weir. The probable cause of the phenomenon will be discussed in detail in the later subsection which describes the results of the Sludge Jet Test on Stamford's clarifier #2. Originally, the phenomenon was termed "solids wave". The interpretation is now believed to be incorrect.

The Peripheral Baffle--

The interpretation of the three-part hydraulic test series was based primarily on the periodic character of Multi-Point Dispersion Test plots, Figures 142 through 144. Flow Pattern/Solids Distribution Test data, Figures 149 and 152, and on the Weir-Wall Solids Test results at 3.75 ft (1.143 m), Figure 154.

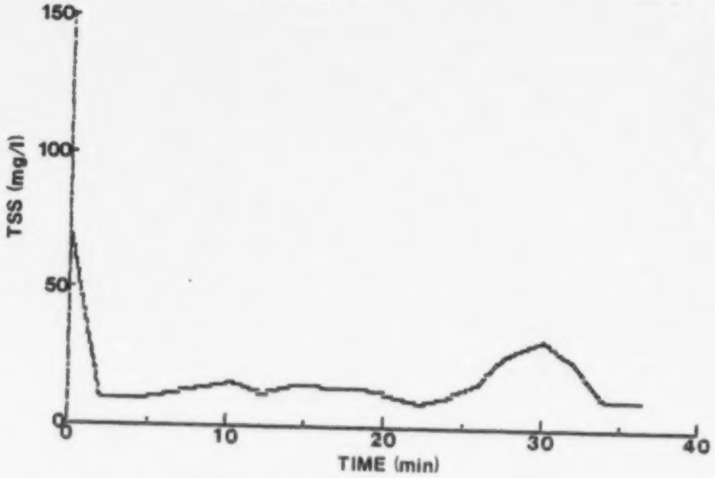


Figure 153. Weir-Wall Solids Concentration versus Time at a depth of 1 ft (0.3 m), Stamford secondary clarifier #1, 8 August 1979. As explained in the text, this plot is not believed to contain reliable data.

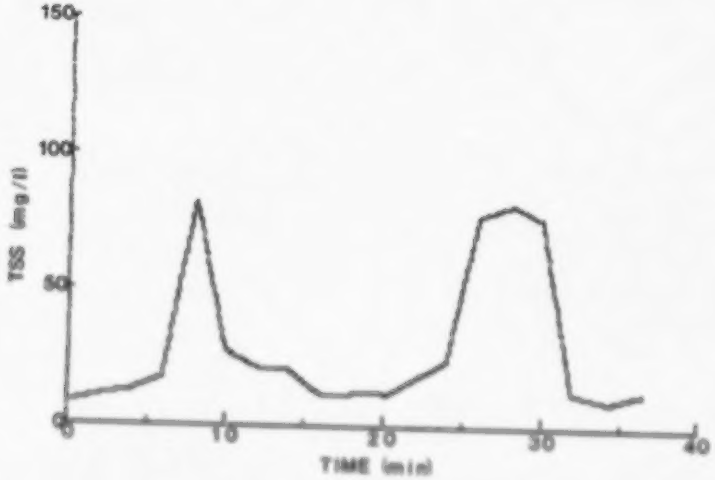


Figure 154. Weir-Wall Solids Concentration versus Time at a depth of 3.75 ft (1.1 m), Stamford secondary clarifier #1, 8 August 1979. Average value is 28.8 mg/l.

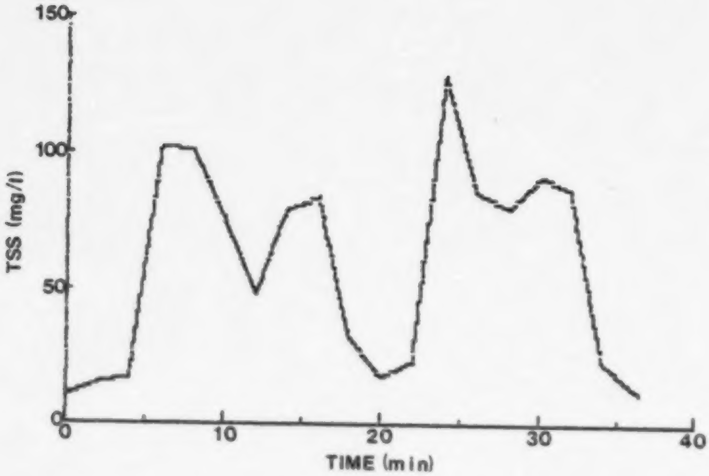


Figure 155. Weir-Wall Solids Concentration versus Time at a depth of 6.5 ft (2.0 m), Stamford secondary clarifier #1, 8 August 1979. Average value is 58.6 mg/l.

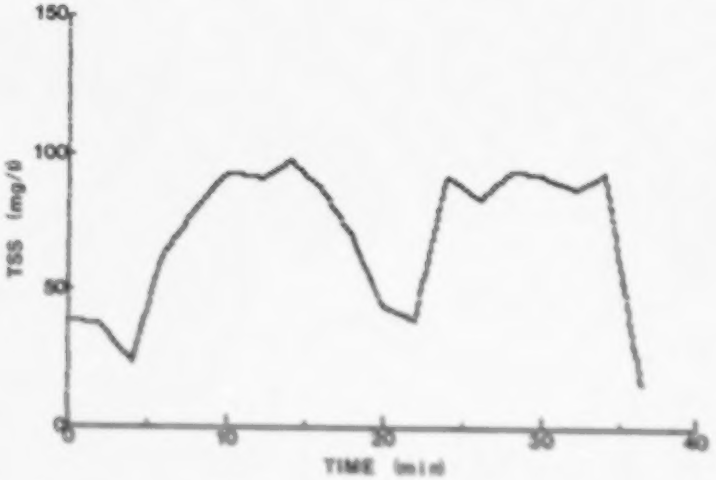


Figure 156. Weir-Wall Solids Concentration versus Time at a depth of 9.25 ft (2.8 m), Stamford secondary clarifier #1, 8 August 1979. Average value is 69.6 mg/l.

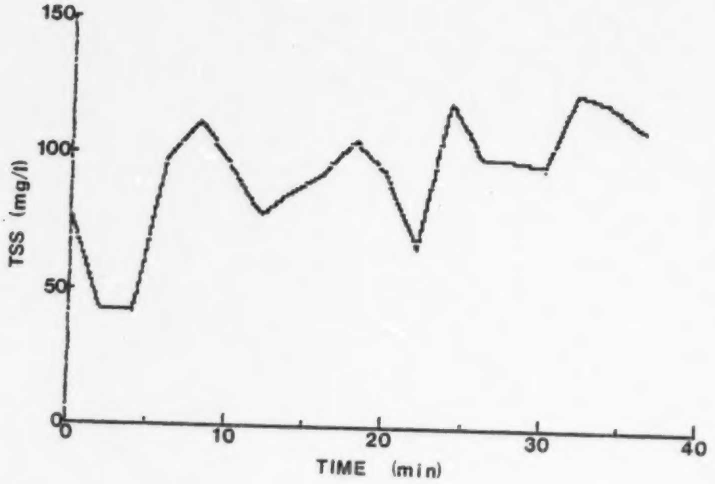


Figure 157. Weir-Wall Solids Concentration versus Time at a depth of 12.0 ft (3.66 m), Stamford secondary clarifier #1, 8 August 1979. Average value is 92.5 mg/l.

TABLE 23. PROCESS DATA ON THE TEST CLARIFIER, STAMFORD, CT, 8 AUGUST 1979

MLTSS	2280 mg/l
Effluent TSS (grab)	89 mg/l
SVI	83

The major performance-degrading problem appeared to be upflow on the peripheral wall, with a periodic enhancement of upflow associated with sludge header rotation. It was decided to install a deflection baffle on the peripheral wall of #1 secondary, several feet (about 1.5 m) below the overflow weir. A portion of the prototype baffle, constructed of a pine framework and marine plywood, is illustrated in Figure 158. The baffle surface slopes downward at 45 degrees in an attempt to minimize solids deposition.

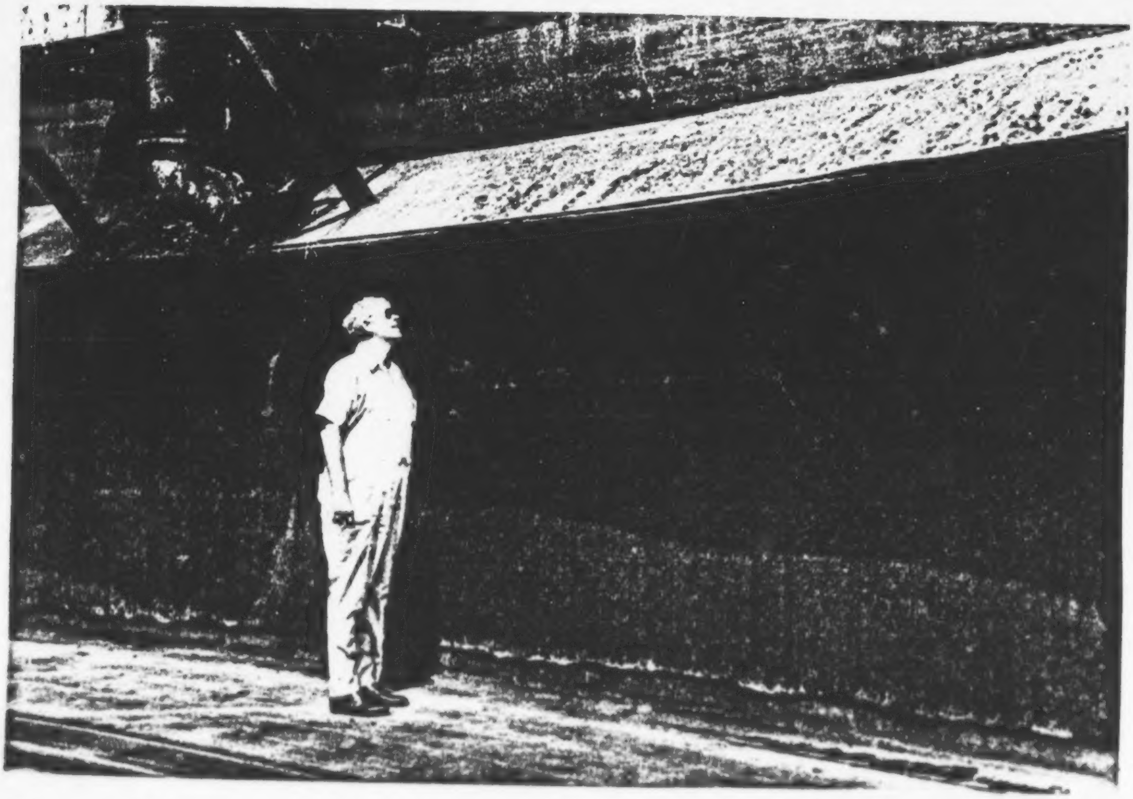


Figure 158. Photograph of the prototype peripheral baffle installed in Stamford secondary clarifier #1, 3 January 1980. At the time of the photograph, September 1980, the baffle had been in service for about 9 months. For scale, the person in the photograph is 6.25 ft (1.9 m) tall;

Final Hydraulic Tests, Clarifier #1--

Before starting the test series, weirs were leveled on the still surface of clarifier #1 after shutdown. A Multi-Point Dispersion Test was conducted on 7 January 1980, after baffle installation. Effluent rate on test clarifier #1 was 9.77 mgd (36,970 m^3/d). This corresponds to a surface area overflow rate of 736 gpd/sq ft (29.98 $m^3/m^2 \cdot d$). Underflow rate was estimated to be 2.3 mgd (8,700 m^3/d). The sludge blanket was clearly definable by optical sensor at a depth of 12 ft (3.7 m) at 1030, just before the start of the test. At 1450, the blanket was more diffuse, and not definable. Winds were gusty, at 20-35 mph (32-56 km/h) from the general direction of sampling stations A and F. The test began at 1049 and ended at 1450.

After release of 1000 ml of Rhodamine WT dye, samples were retrieved at the six peripheral stations, as they were during the 6 August test. Physical data pertinent to the dispersion test are summarized in Table 24. The six Multi-Point Dispersion plots are shown in Figures 159 through 164. The time scale for these plots is the same as for the pre-modification test of 6 August. The non-dimensional concentration scale has been compressed because of the higher values encountered on 7 January 1980. As before, an "average dispersion curve" was calculated, as shown in Figure 165.

TABLE 24. PHYSICAL DATA PERTINENT TO THE DISPERSION TEST ON STAMFORD SECONDARY CLARIFIER #1, 7 JANUARY 1980

Background fluorescence = 0.6 ppb
Tank volume = 1,470,000 gal
Effluent rate during test = 9.77 mgd
Estimated underflow rate during test = 2.3 mgd
Retention time based on influent rate, T_O = 176.1 min
500 ml of dye added to test clarifier only
Flash mix fluorescence, C_O = 89.9 ppb

Weir Station	Relative Dye Mass Overflowing weir Station	Median Retention Time for This Test (min)
A	0.595	118.5
B	0.696	97.3
C	0.739	93.2
D	0.765	86.4
E	0.734	91.0
F	0.682	102.0

Process samples were retrieved twice on the dispersion test day. The results of laboratory tests on these samples are shown in Table 25.

Two features of the dispersion test are of interest:

1. The effect of wind on the transport of tracer may be significant. A greater mass of dye overflowed downwind sampling stations B through E. Median retention time was less for these stations as well.

2. The prominent peaks which correlated with sludge header rotation during the 6 August 1979 test were diminished on 7 January 1980.

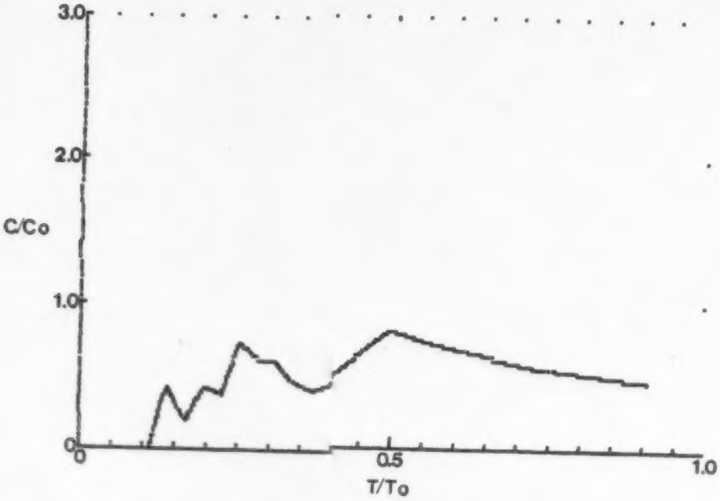


Figure 159. Results of the Multi-Point Dispersion Test of Stamford secondary clarifier #1, weir station A, 7 January 1980.

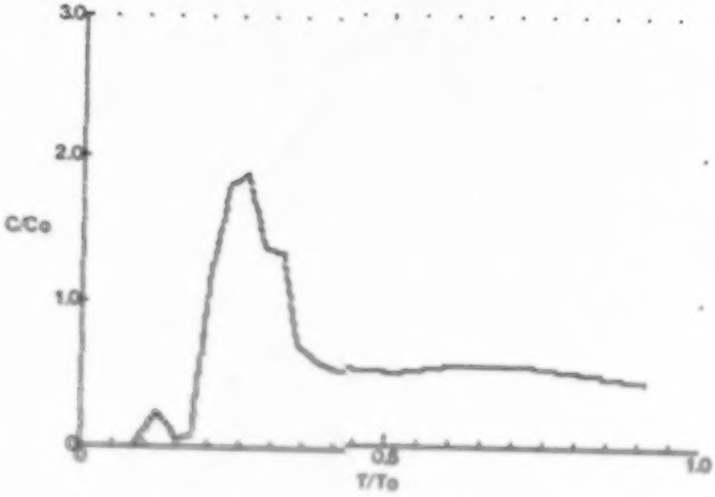


Figure 160. Results of the Multi-Point Dispersion Test of Stamford secondary clarifier #1, weir station B, 7 January 1980.

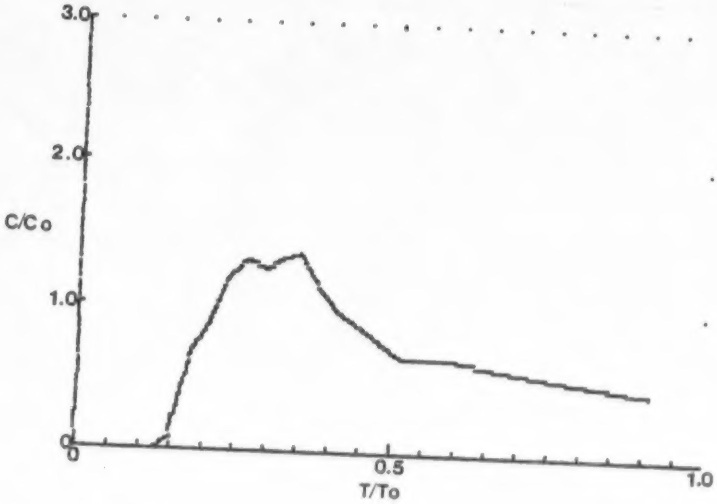


Figure 161. Results of the Multi-Point Dispersion Test of Stamford secondary clarifier #1, weir station C, 7 January 1980.

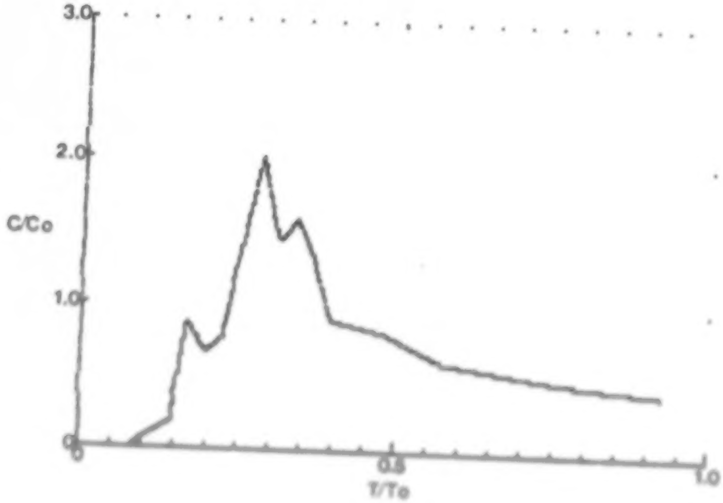


Figure 162. Results of the Multi-Point Dispersion Test of Stamford secondary clarifier #1, weir station D, 7 January 1980.

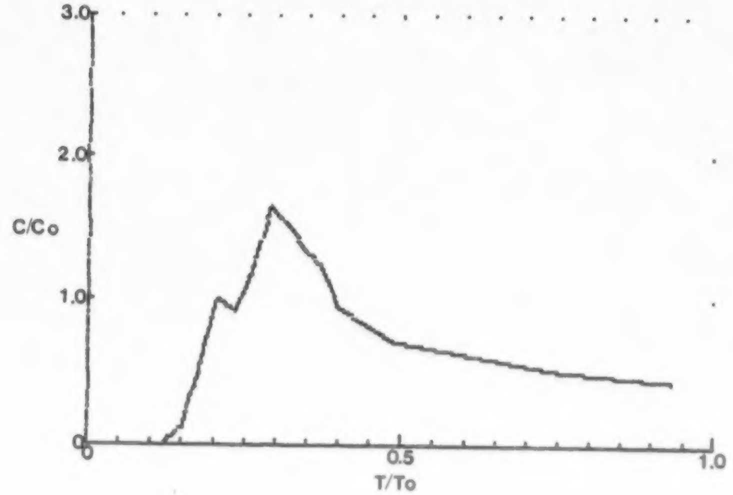


Figure 163. Results of the Multi-Point Dispersion Test of Stamford secondary clarifier #1, weir station E, 7 January 1980.

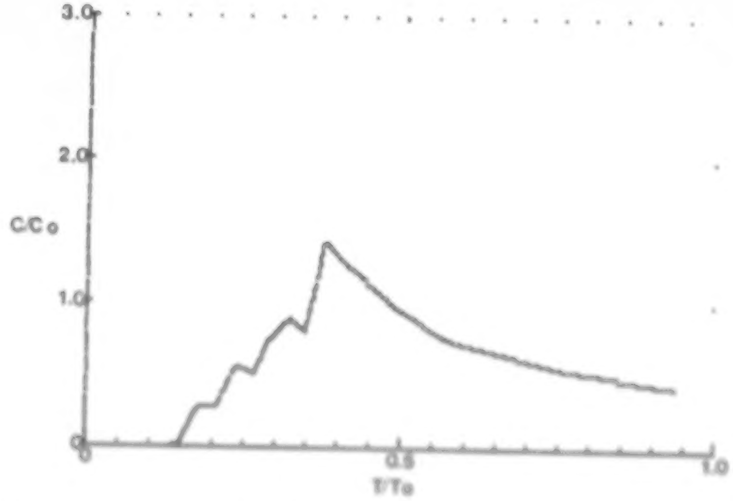


Figure 164. Results of the Multi-Point Dispersion Test of Stamford secondary clarifier #1, weir station F, 7 January 1980.

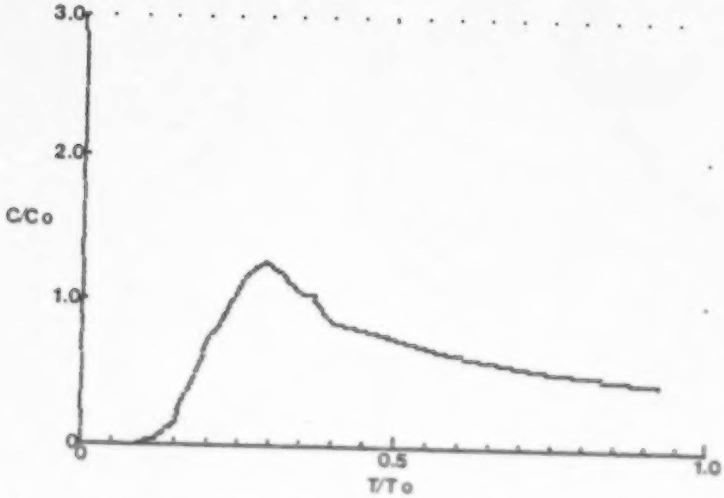


Figure 165. Average result of the Multi-Point Dispersion Test of the Stamford secondary clarifier #1, 7 January 1980.

A Flow Pattern/Solids Distribution Test was run on 8 January 1980. Overflow rate for clarifier #1 was 8.65 mgd (32,740 m^3/d). This is a surface area overflow rate of 652 gpd/sq ft (26.56 $m^3/m^2 \cdot d$). Underflow was estimated to be 2.2 mgd (8,500 m^3/d). At 1000, just before the test began, the blanket was at 12 ft (3.7 m) by optical sensor with a diffuse layer about 1 ft (0.3 m) thick above the interface. Winds were calm on this day. Dye was started at 1048 as the skimmer (and one header arm) passed the bridge sampling section. The three flow pattern runs were at 1106, 1124 and 1142. The test results are presented in Figures 166-169. Related process data for the day are presented in Table 26.

The flow patterns measured on 8 January 1980, after baffle installation, were different from the earlier test series. Figure 166 shows that little upflow occurred on the peripheral wall. Figure 168 suggests that some upflow occurred at mid-radius and just outside the feedwell. In Figure 169, a relatively level solids distribution had developed. In this post-modification flow pattern series, the peripheral sampling station, #5, was moved slightly toward the center of the tank and away from the scum baffle to avoid the deep baffle structure. Thus, data from the upper right-hand sampling point were believed to be valid. The solids distribution plots in Figures 167 and 169 are not directly comparable; data contours in the latter figure are square-roots of total suspended solids.

TABLE 25. PROCESS DATA ON THE TEST CLARIFIER, STAMFORD, CT, 7 JANUARY 1980

MLTSS @ 0800 2060 mg/l

Settleometer Test

Time (min)	Settled Sludge Volume (ml/l)	
5	475	
10	365	
15	325	
30	260	SVI = 126
50	230	

MLTSS @ 1300 1600 mg/l

Settleometer Test

Time (min)	Settled Sludge Volume (ml/l)	
5	325	
10	240	
15	215	
30	180	SVI = 113
50	160	

Effluent TSS (6 hour composite), clarifier #1 11 mg/l
Effluent TSS (6 hour composite), clarifier #2 17 mg/l

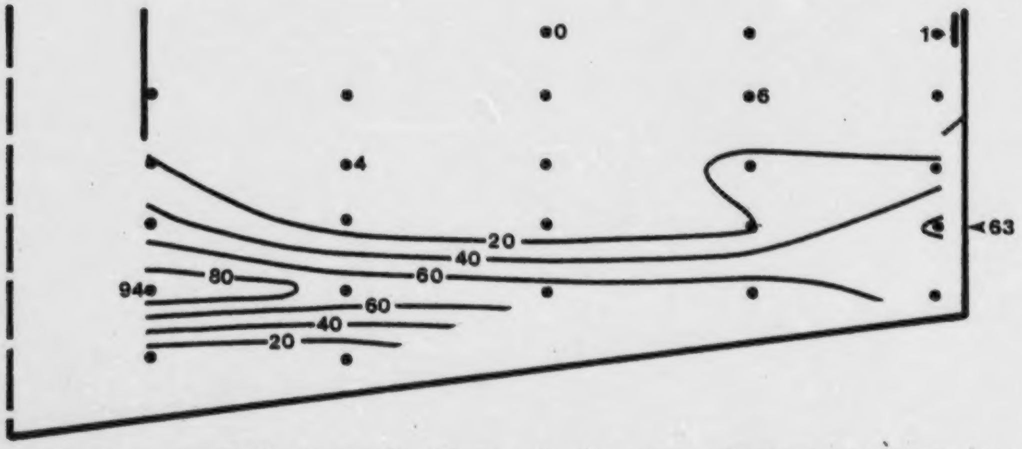


Figure 166. Radial distribution of the dye concentrations in Stamford secondary clarifier #1, 20 min after the start of continuous dye injection, 8 January 1980.

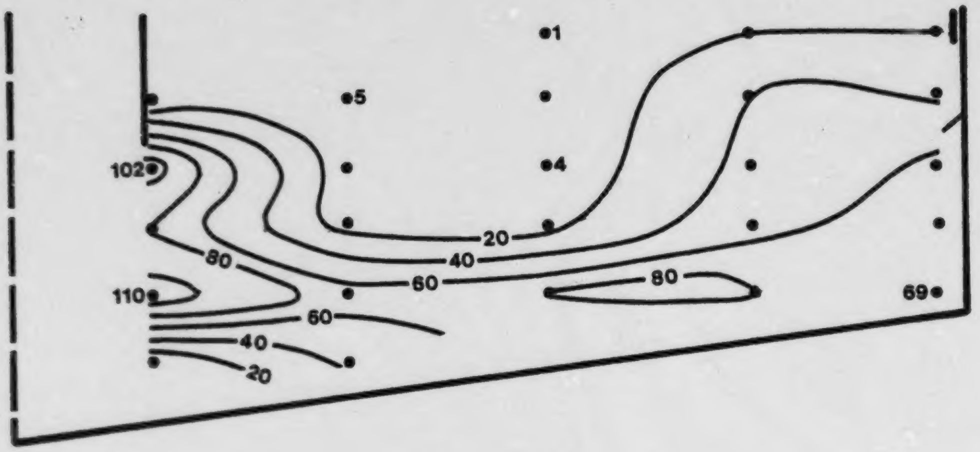


Figure 167. Radial distribution of the dye concentrations in Stamford secondary clarifier #1, 38 min after the start of continuous dye injection, 8 January 1980.

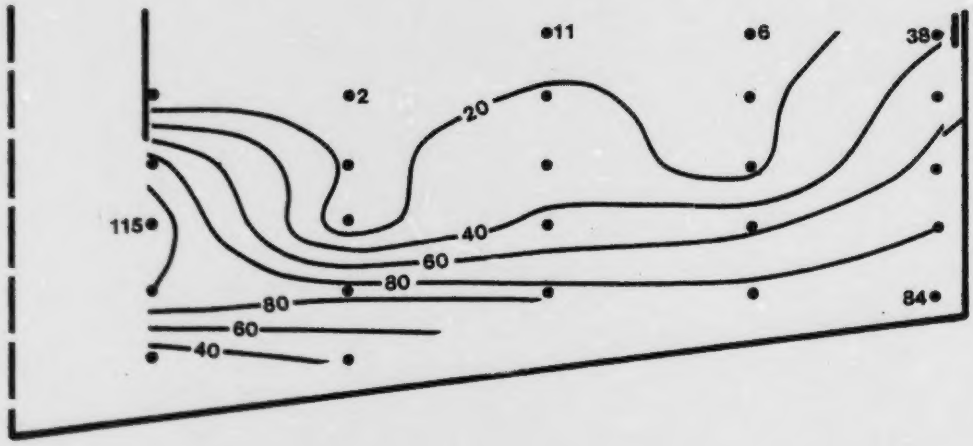


Figure 168. Radial distribution of the dye concentrations in Stamford secondary clarifier #1, 55 min after the start of continuous dye injection, 8 January 1980.

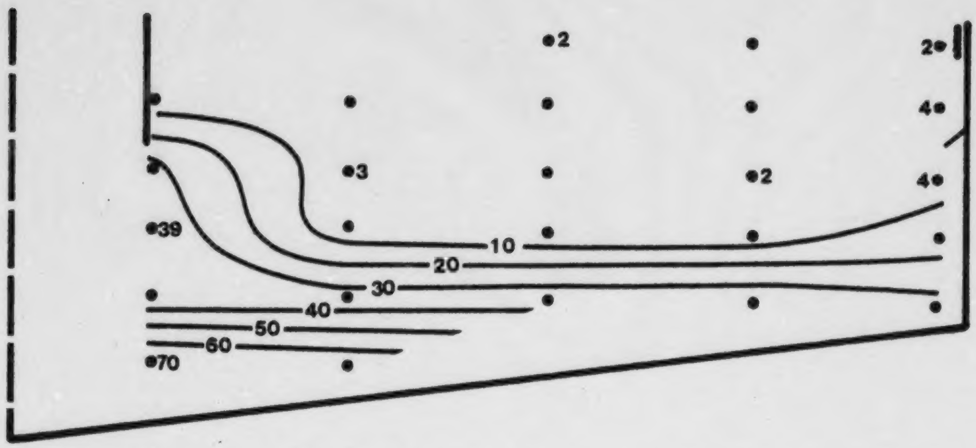


Figure 169. Radial distribution of the square-root of total suspended solids in Stamford secondary clarifier #1, 8 January 1980.

TABLE 26. PROCESS DATA ON THE TEST CLARIFIER, STAMFORD, CT, 8 JANUARY 1980

MLTSS @ 0830	1960 mg/l

Settleometer Test

Time (min)	Settled Sludge Volume (ml/l)	
5	460	
10	365	
15	320	
30	260	SVI = 133
50	230	

MLTSS @ 1300	2120 mg/l

Settleometer Test

Time (min)	Settled Sludge Volume (ml/l)	
5	480	
10	375	
15	335	
20	300	
30	270	SVI = 127
50	230	
60	220	

Effluent TSS (6 hour composite), clarifier #1	8.5 mg/l
Effluent TSS (6 hour composite), clarifier #2	10 mg/l

A modified Weir-Wall Solids Test was conducted on 9 January 1980. Overflow rate for the test clarifier was 7.89 mgd (29,860 m^3/d). This is a surface area overflow rate of 594 gpd/sq ft (24.19 $m^3/m^2 \cdot d$). Underflow was estimated to be 2.2 mgd (8,500 m^3/d). At 0936, a blanket interface could be defined, by optical sensor, at 12 ft (3.7 m), but there was a diffuse layer of suspended solids to within 2 ft (0.6 m) of the surface at station 3.

The sampling locations for the post-modification Weir-Wall Solids Test were changed to those points defined in Figure 170, near station 5. Figure 170 shows the 13 ft (4.0 m) deep side-wall, peripheral deflection baffle and sample points to scale. Only point A is the same as for the pre-modification Weir-Wall Solids Test. Test results are presented in Figures 171 through 173. Vertical scale on these plots is equivalent to the pre-modification test results, Figures 153 through 157.

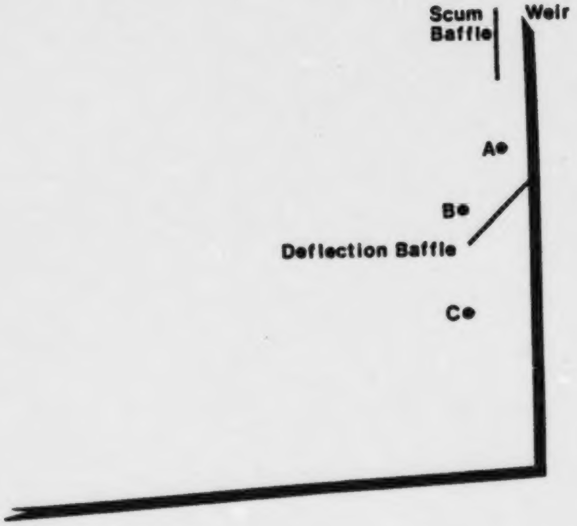


Figure 170. Scale drawing showing the positions of the peripheral deflection baffle and sampling points for the post-modification Weir-Wall Solids Test at station 5, Stamford secondary clarifier #1, 9 January 1980.

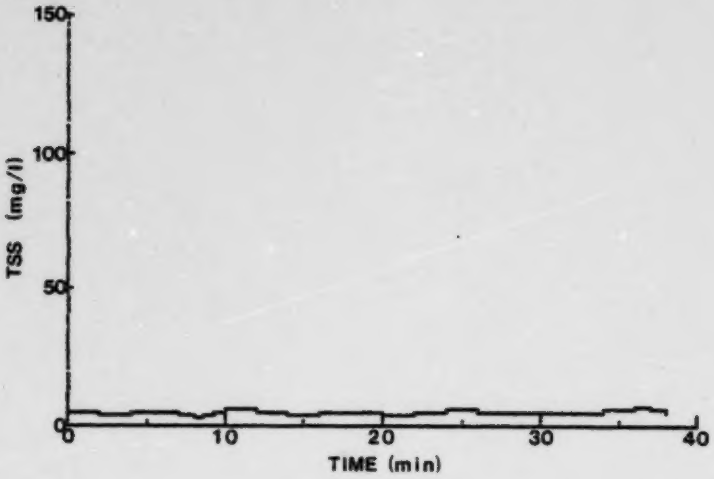


Figure 171. Weir-Wall Solids Concentration versus Time at a depth of 3.75 ft (1.1 m), point A, Stamford secondary clarifier #1, 9 January 1980. Average value is 5.0 mg/l.

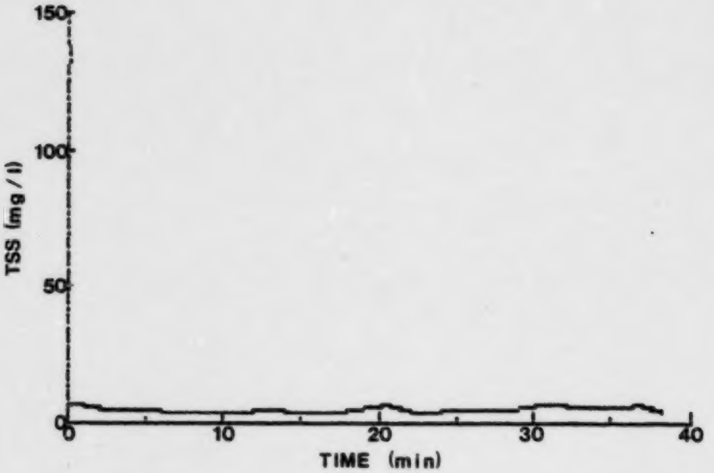


Figure 172. Weir-Wall Solids Concentration versus Time at a depth of 5.56 ft (1.7 m), point B, Stamford secondary clarifier #1, 9 January 1980. Average value is 5.2 mg/l.

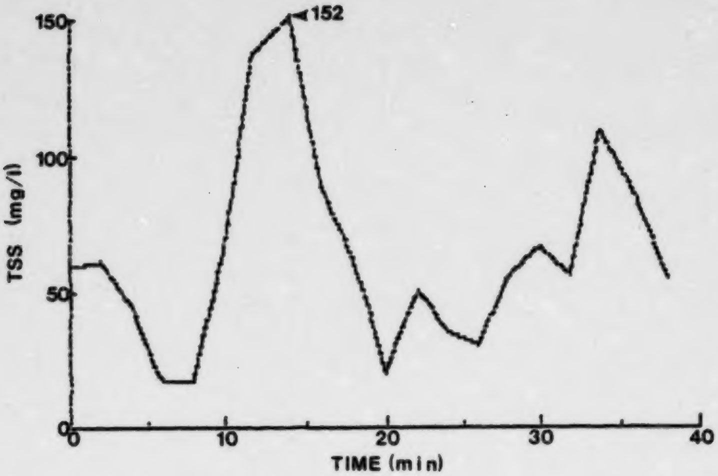


Figure 173. Weir-Wall Solids Concentration versus Time at a depth of 8.56 ft (2.609 m), point C, Stamford secondary clarifier #1, 9 January 1980. Average value is 63.5 mg/l.

It is apparent from Figures 171 and 172 that the periodic solids rise on the peripheral wall did not occur above the new baffle.

Process data for the day of the Weir-Wall Solids Test are presented in Table 27.

TABLE 27. PROCESS DATA ON THE TEST CLARIFIER, STAMFORD, CT, 9 JANUARY 1980

MLTSS 2220 mg/l

Settleometer Test

Time (min)	Settled Sludge Volume (ml/l)	
5	505	
10	390	
15	310	
20	310	
30	275	SVI = 124
50	240	
60	230	

Effluent TSS (6 hour composite), clarifier #1	8 mg/l
Effluent TSS (6 hour composite), clarifier #2	9 mg/l

Peripheral Baffle Performance--

A comparative performance evaluation between newly baffled secondary clarifier #1 and unmodified secondary clarifier #2 was conducted from 7 January until 2 April 1980. During this period, there were 52 days of complete data sets, including the following information:

- Plant flow totalizer morning reading and time of reading
- Plant flow totalizer afternoon reading and time of reading
- Effluent TSS composite, 0900-1500, clarifier #1
- Effluent TSS composite, 0900-1500, clarifier #2
- Percent return sludge rate
- MLTSS
- SVI
- Depth to blanket, clarifier #1
- Depth to blanket, clarifier #2

Plant flow rate for the peak flow hours was calculated from totalizer readings. The return sludge flowmeter was later found to be inoperative although it gave a convincing output reading of 30%, the normal rate "set" by the operator each day. Effluent TSS samples were composited only during peak flow hours because clarifier-to-clarifier mixed liquor feed rate was balanced only during normal peak flows by partially closing the gate valve to secondary #2.

Although the comparative test under control of the author concluded on 2 April, with 52 data sets, the plant's laboratory personnel continued to collect data until 7 October 1980, for a total of 144 data sets. A complete data listing is provided in Appendix F. Because of uncertainty regarding hydraulic and process conditions for data sets 53 through 144, only the first 52 were used in the performance comparison. A summary of the results is shown in Table 28.

Records of plant flow and effluent TSS from the two clarifiers are superimposed in Figures 174 and 175.

TABLE 28. SUMMARY OF STAMFORD BAFFLE PERFORMANCE EVALUATION DATA, 7 JANUARY - 2 APRIL 1980, 52 DATA SETS

	Average
Plant flow (mgd)	23.444
MLTSS (mg/l)	2206
SVI	135
Depth to blanket, clarifier #1 (ft)	13.1
Depth to blanket, clarifier #2 (ft)	11.7
Effluent TSS, clarifier #1 (mg/l)	11.65
Effluent TSS, clarifier #2 (mg/l)	18.89
Settled Sludge Volume, 5 min (%)	54.8

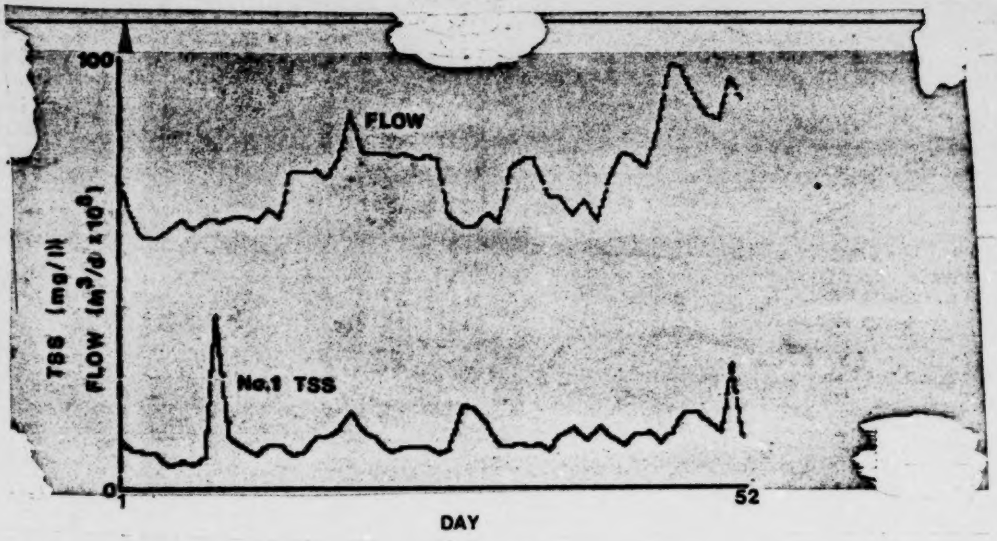


Figure 174. Total plant flow and secondary clarifier #1 effluent TSS during the 52 day baffle performance evaluation, Stamford, CT, 7 January 1980 - 2 April 1980.

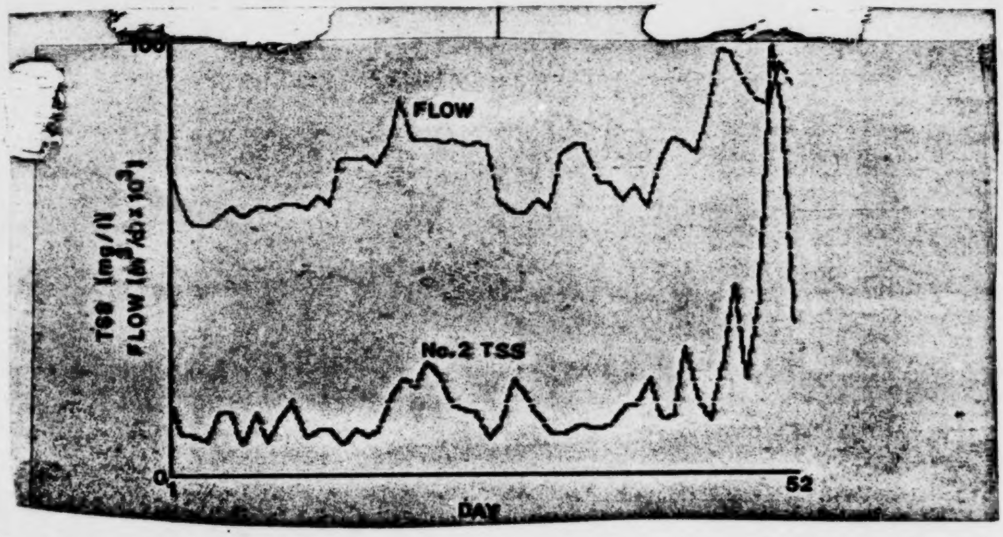


Figure 175. Total plant flow and secondary clarifier #2 effluent TSS during the 52 day baffle performance evaluation, Stamford, CT, 7 January 1980 - 2 April 1980.

At this stage of the study, it was believed that the settled sludge volume in 5 min (SSV_5) from the daily settleometer test might prove to be more predictive of clarifier performance than SVI. Plots of SSV_5 versus effluent TSS of the two secondaries are presented in Figures 176 and 177.

The data show that secondary clarifier #1, with the baffle, has a lower effluent TSS than #2, 11.65 mg/l versus 18.89 mg/l, a difference of 38.3%. The blanket in #2 was somewhat higher, however.

The cost of labor and material for the peripheral baffle at Stamford was approximately $3000. Structural design was by Stearns and Wheler, Consulting Engineers, Darien CT, with general direction by the principal investigator.

Hydraulic Tests, Clarifier #2--

The tests on Stamford's secondary clarifier #2 were intended to be a comprehensive study of the physical and process related factors which affect the transport of solids within a large center feed, peripheral overflow circular activated sludge secondary clarifier of "common" design. If the reader has taken the opportunity to review the results from the five center feed circular clarifiers already presented, he will understand the investigator's quotation marks on the term "common". Although the units seem to be physically similar, it is apparent that numerous factors upstream and within the tanks influence their hydraulic behavior and the quality of effluent discharged. Thus, it should be understood that the results to be presented in this subsection may apply only to clarifiers which are very similar to this one in structural detail, in a process with similar sludge quality.

A clear understanding of the inlet design of the Stamford secondaries is important to the reader's interpretation of the results. Details of this design are most easily visualized by referring to Figure 178. The cylindrical column in the center of the photograph is 4 ft (1.2 m) in diameter. Four rectangular inlet ports introduced mixed liquor to the tank. Mixed liquor flow is upward within the center column. A smaller concentric pipe, inside the 4 ft (1.2 m) column, is the main return sludge line for this clarifier. The ten riser pipes, parts of which are visible in the photograph, bring the return sludge from various radial locations on the bottom to a central sump. In operation, the 4 ft (1.2 m) diameter inlet column remains stationary. All other elements visible in the photograph rotate. An overall view of one riser pipe/scraper arm is shown in Figure 179.

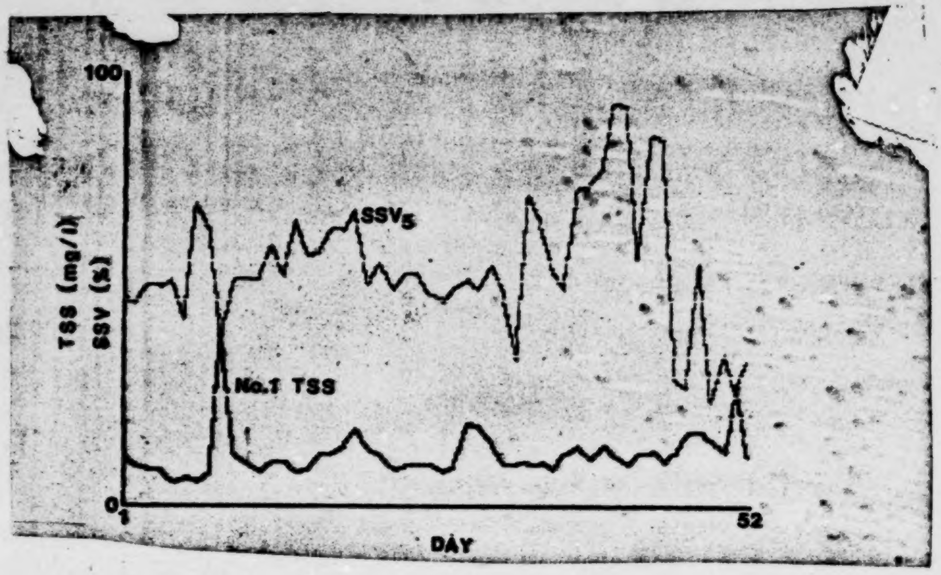


Figure 176. SSV_5 and secondary clarifier #1 effluent TSS during the 52 day baffle performance evaluation, Stamford, CT, 7 January 1980 - 2 April 1980.

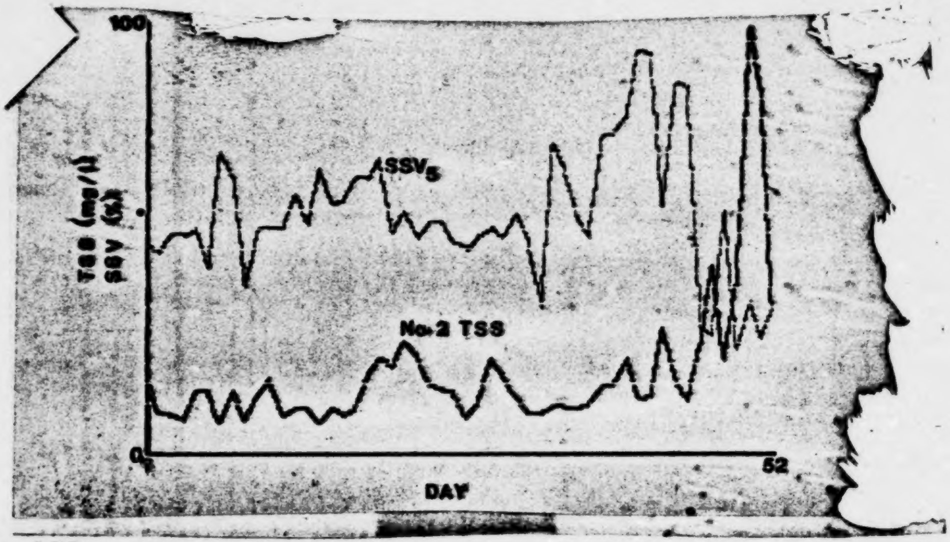


Figure 177. SSV_5 and secondary clarifier #2 effluent TSS during the 52 day baffle performance evaluation, Stamford, CT, 7 January 1980 - 2 April 1980.

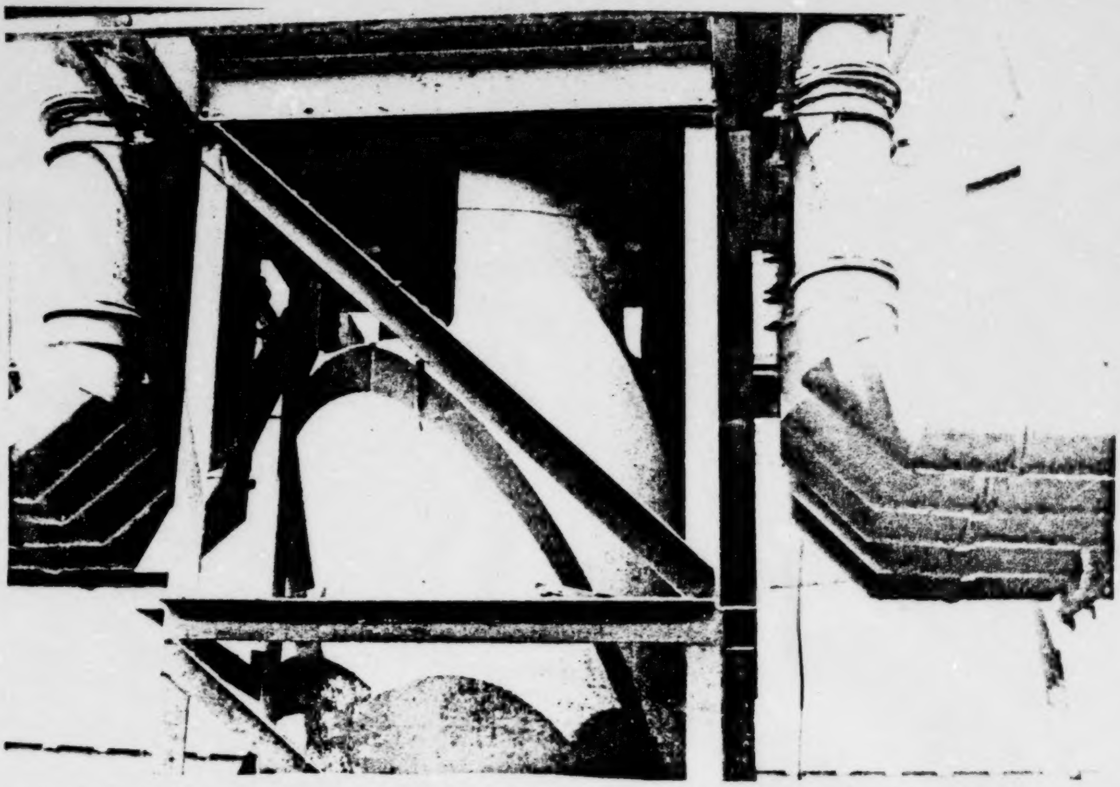


Figure 178. A view of the inlet region of one of the Stamford secondary clarifiers.

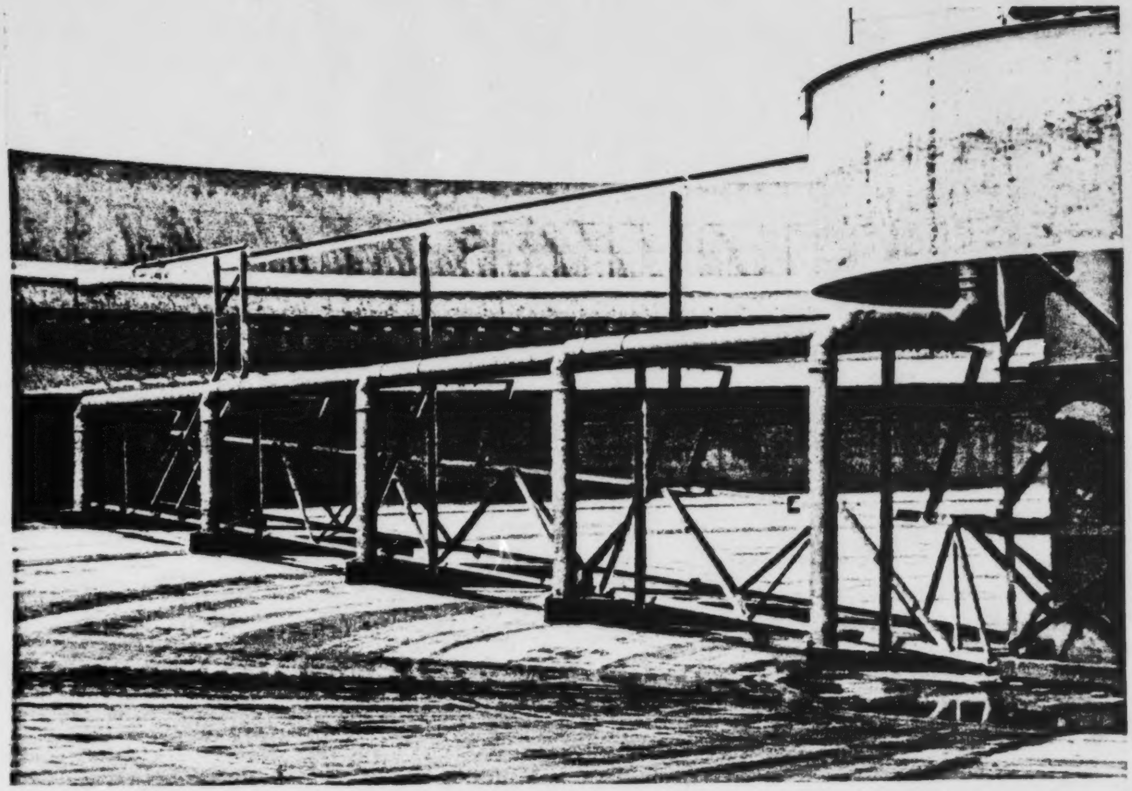


Figure 179. A view of one of the two riser pipe/scraper arms in Stamford secondary clarifier #1. The peripheral baffle is visible in the background. Except for the baffle, the clarifier shown is structurally identical to secondary #2.

A Sludge Jet Test series was conducted to confirm the suspected radial persistence of solids jets from the four fixed-direction inlet ports. The dispersion part of the test was carried out on 21 October 1980. Effluent rate of secondary clarifier #2 was 8.70 mgd (32,930 m^3/d), a surface area overflow rate of 655 gpd/sq ft (26.68 $m^3/m^2 \cdot d$). Underflow rate was estimated to be 2.7 mgd (10,333 m^3/d). The sludge blanket was at the bottom at mid-radius, just after passage of one riser pipe arm. Tank depth at mid-radius is 15.5 ft (4.72 m).

After sludge dye release upstream, sludge samples were taken in the combined underflow central sump, at which point the return sludge from the 10 riser pipes has mixed, and from one of the two riser pipes which lifts sludge from mid-radius. Sampling interval was 2 min for the first 30 min, then at longer intervals for a test duration of 2 hours. The results of the sludge dispersion test, plotted as dye concentration versus time, are presented in Figures 180 and 181.

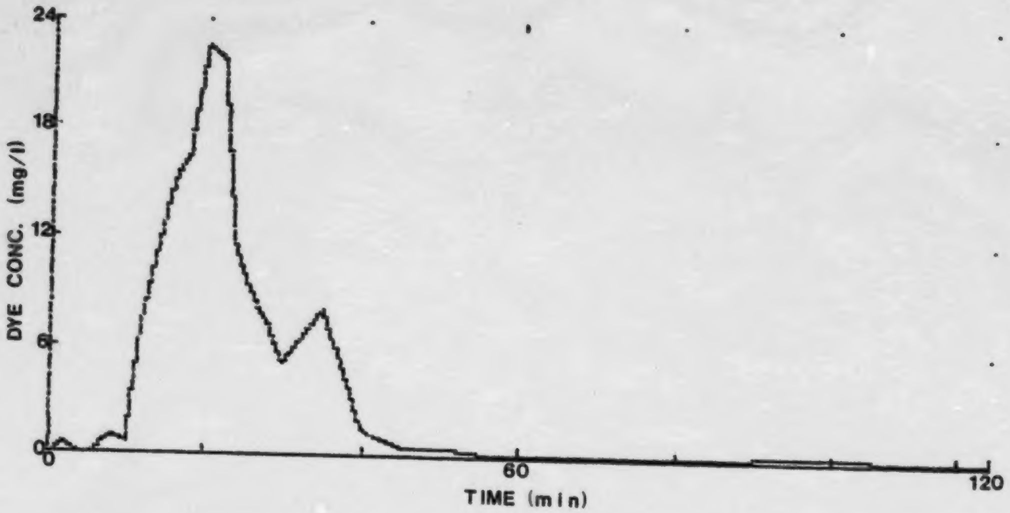


Figure 180. Plot of sludge dye concentration versus time for the combined underflow from the central sump of Stamford secondary clarifier #2, 21 October 1980.

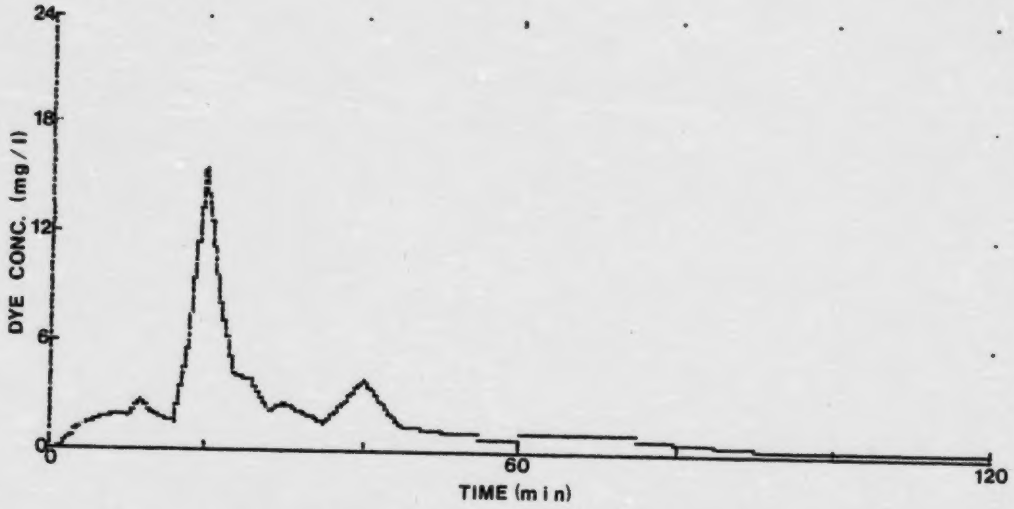
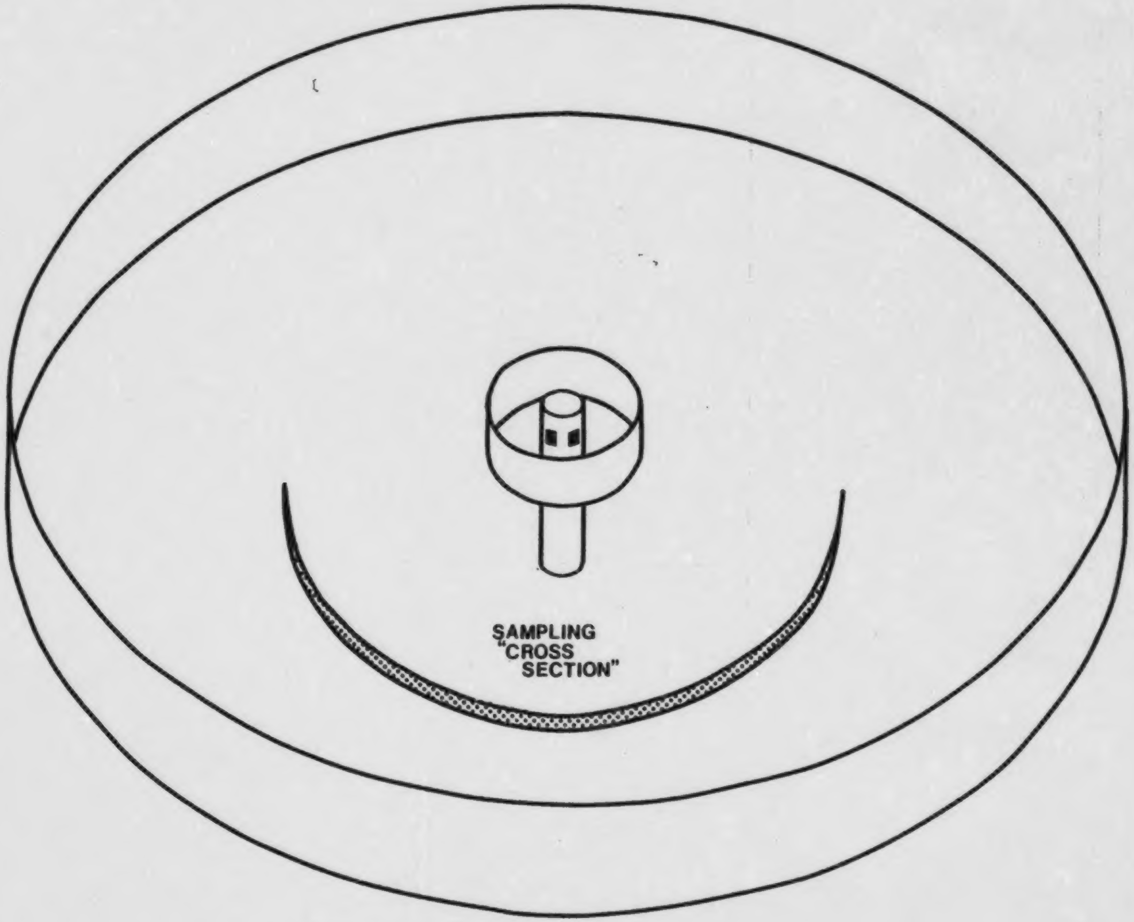


Figure 181. Plot of sludge dye concentration versus time for the sludge returned from one mid-radius riser pipe, Stamford secondary clarifier #2, 21 October 1980.

For the second part of the Sludge Jet Test series, 30 discrete samplers were arrayed in the region shown to scale, shaded, in Figure 182. The sludge header mechanism was stopped so that the two sets of 5 riser pipes obscured one diametrically opposed



SAMPLING
"CROSS
SECTION"

Figure 182. Simplified scale drawing of Stamford secondary clarifier #2 showing the relationship between the feedwell and inlet ports and the Sludge Jet Test "cross section", shown shaded.

pair of mixed liquor inlet ports. The other pair of inlet ports was not obscured. The mid-radius sampling stations, covering 147 degrees of arc, bracketed one obscured and one unobscured inlet port.

Clarifier effluent rate was controlled at 8.70 mgd (32,930 m^3/d). This is a surface area overflow rate of 655 gpd/sq ft (26.68 $m^3/m^2 \cdot d$). Underflow was shut down. Two minutes before dye release, the blanket was at 13.3 ft (4.05 m) at bridge station 3, by optical sensor. Twenty minutes after dye release at the splitter box upstream of the clarifier, all samplers were tripped within a period of 2 min.

The 30 samples were analyzed for sludge dye concentration and for total suspended solids. The results, with an exaggerated vertical scale, are presented in Figures 183 and 184.

Figure 183 clearly shows the directional influence of the mixed liquor inlet ports on initial distribution of sludge at blanket depth. The jet from the unobscured ports was more intense than the jet which was obscured by 5 closely spaced riser pipes. The right-hand jet's lower intensity may have resulted from dispersion by the baffle-like header obstruction.

A Multi-Point Dispersion Test was conducted on 19 November 1980. Clarifier #2 effluent rate was controlled at 7.96 mgd (30,140 m^3/d). This is an overflow rate of 600 gpd/sq ft (24.44 $m^3/m^2 \cdot d$). Underflow rate was estimated at 1.6 mgd (6000 m^3/d). The blanket was at a depth of 14.8 ft (4.51 m) by optical sensor. The sludge header mechanism was rotating.

The 12 weir stations for this test were laid out over 180 degrees in order to more clearly show possible directional preferences caused by the inlet ports. After release of 1000 ml of Rhodamine WT dye at the aeration basin discharge, samples were taken at the 12 stations at 3 min intervals for 1 hour and at lesser intervals for a total test duration of about 2.5 hours. Physical data pertinent to the dispersion test is presented in Table 29. The dispersion curves are shown in Figures 185 through 196. The investigator was surprised to find that despite some differences in the appearance of the dispersion plots, the differences between numerical values calculated in Table 29 seem slight.

Flow Pattern/Solids Distribution Tests were conducted on clarifier #2 at surface area overflow rates of 300, 600, 900 and 1050 gpd/sq ft (12.2, 24.44, 36.06 and 42.8 $m^3/m^2 \cdot d$) under normal low blanket conditions and at 600 gpd/sq ft (24.44 $m^3/m^2 \cdot d$) under a high blanket condition. Each of the controlled overflow rate tests consisted of 2 radial section flow pattern "snapshots" and a radial section distribution of the square-root of total suspended solids. All tests were carried out with the riser

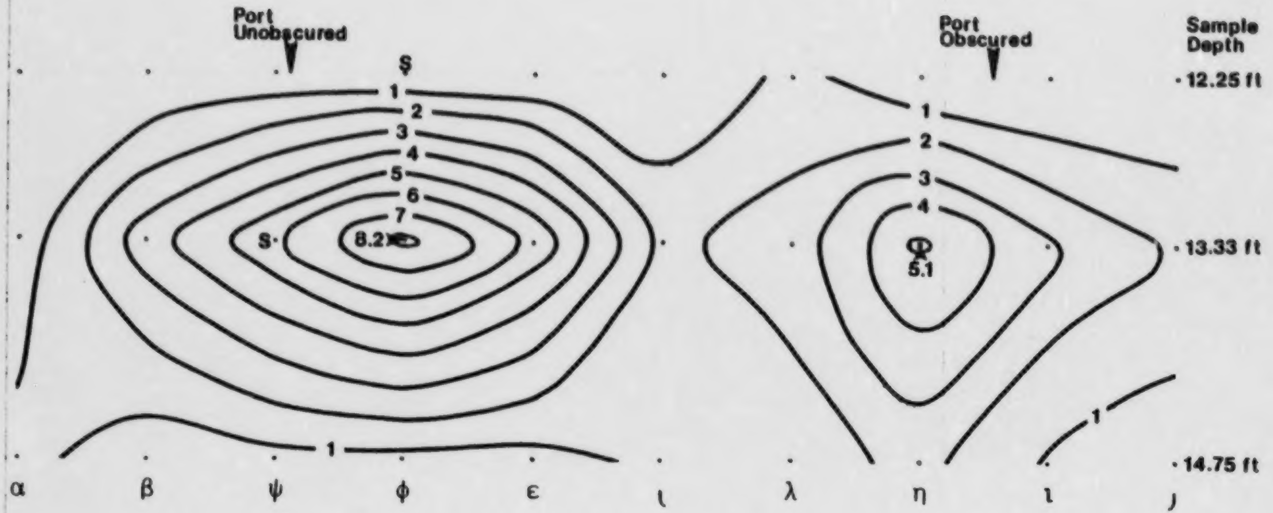


Figure 183. Distribution of sludge dye concentration in a mid-radius section, 20 min after instantaneous dye release, Stamford secondary clarifier #2, 23 October 1980. Vertical scale is exaggerated. Horizontal scale represents 147.3 degrees of arc , or 83.54 ft (25.5 m). The locations of two inlet ports are indicated. Sampling stations are identified by Greek symbols. Points marked "S" were sampling errors; data were interpolated.

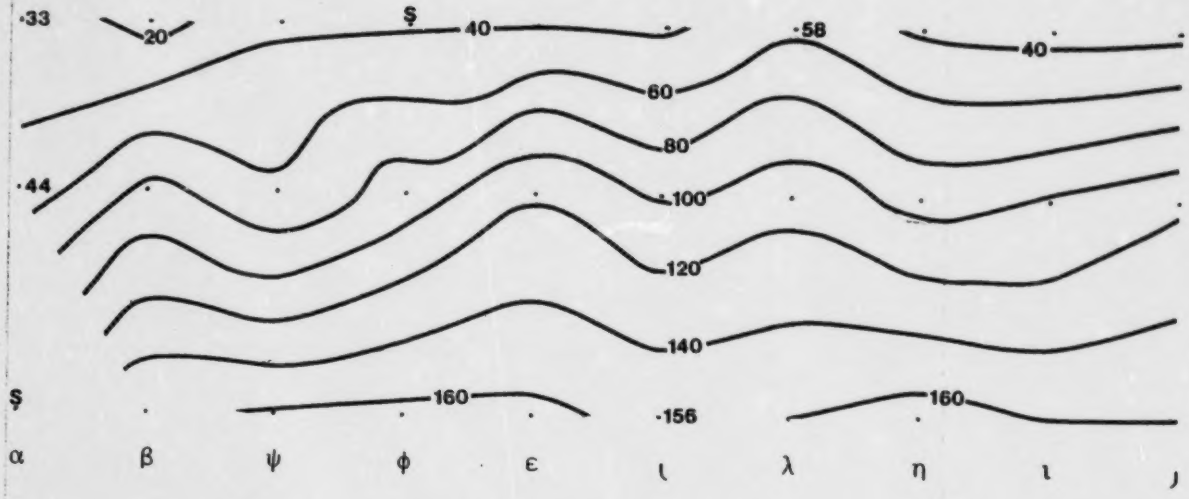


Figure 184. Distribution of the square-root of total suspended solids in a mid-radius section, Stamford secondary clarifier #2, 23 October 1980. Vertical scale is exaggerated. Horizontal scale represents 147.3 degrees of arc, or 83.54 ft (25.5 m). Sampling stations are identified by Greek sumbols. Points marked "S" were sampling errors; data were interpolated.

TABLE 29. PHYSICAL DATA PERTINENT TO THE DISPERSION TEST ON STAMFORD SECONDARY CLARIFIER #2, 19 NOVEMBER 1980

Background fluorescence = 1.1 ppb
Tank volume = 1,470,000 gal
Effluent rate during test = 7.96 mgd
Underflow rate during test = 1.60 mgd
Retention time based on influent rate, T_O = 221.3 min
400 ml of dye added to test clarifier only
Flash mix fluorescence, C_O = 71.9 ppb

Weir Station	Relative Dye Mass Overflowing Weir Station	Median Retention Time for This Test (min)
A	0.442	74.4
B	0.408	79.7
C	0.402	83.6
D	0.410	83.0
E	0.408	82.0
F	0.400	85.0
G	0.423	83.0
H	0.410	82.2
I	0.436	80.0
J	0.444	79.3
K	0.442	79.9
L	0.416	80.4

pipe mechanism stopped at 90 degrees to the access bridge, thus, the test section was in line with an unobscured inlet port. To enhance comparability, the first sample set was always taken 20 min after the start of continuous dye injection; the second sample set was taken at 43 min after the start of the dye. Each set of 34 samples required about 30 seconds for retrieval, using discrete sampler arrays. Further, all dye data were corrected for background fluorescence and normalized to a maximum detected dye concentration for each test series of 100 ppb in the feedwell. This correction measure was necessary because total plant flow rate was not determined; thus the dye dilution in the total flow to the splitter box which feeds both secondary clarifiers was unknown. Although the flow rate to the first clarifier, #2, was controlled and measured, #1 clarifier, uncontrolled, received the balance of the total plant flow.

Test results are presented in order of ascending surface area overflow rate. Physical and process data pertinent to all the tests are summarized in Table 30. The contoured Flow Pattern/Solids Distribution Test results are shown in Figures 197 through 211.

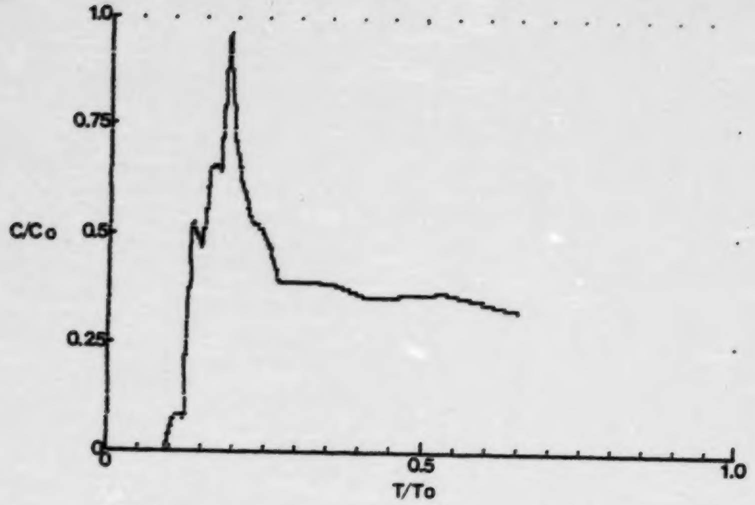


Figure 185. Results of the Multi-Point Dispersion Test of Stamford secondary clarifier #2, weir station A, 19 November 1980.

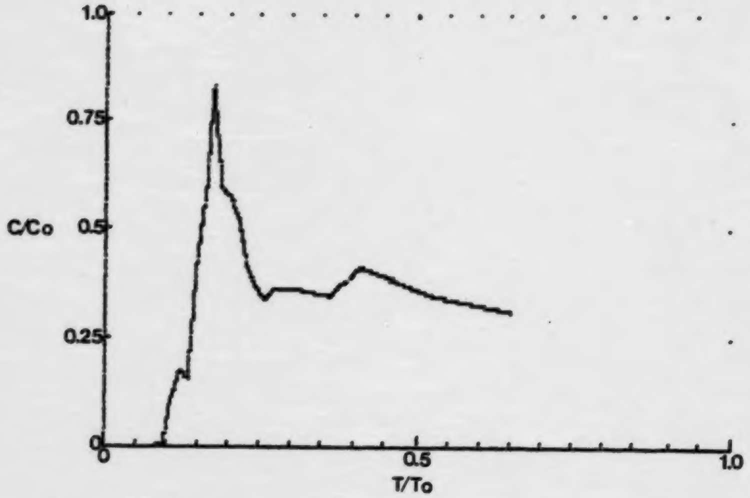


Figure 186. Results of the Multi-Point Dispersion Test of Stamford secondary clarifier #2, weir station B, 19 November 1980.

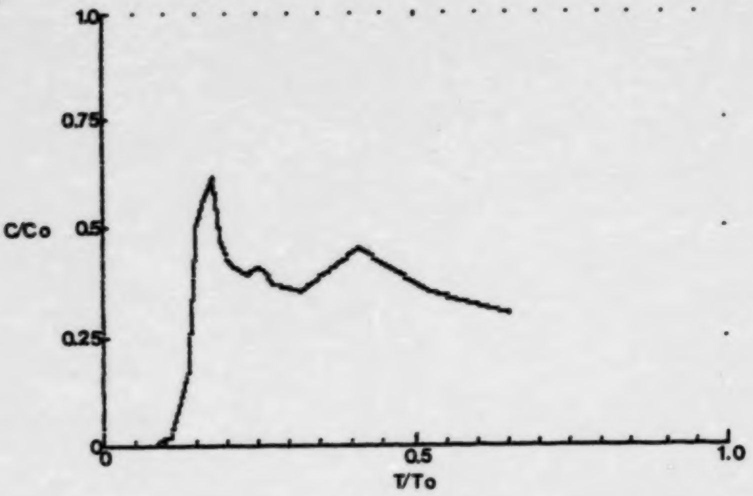


Figure 187. Results of the Multi-Point Dispersion Test of Stamford secondary clarifier #2, weir station C, 19 November 1980.

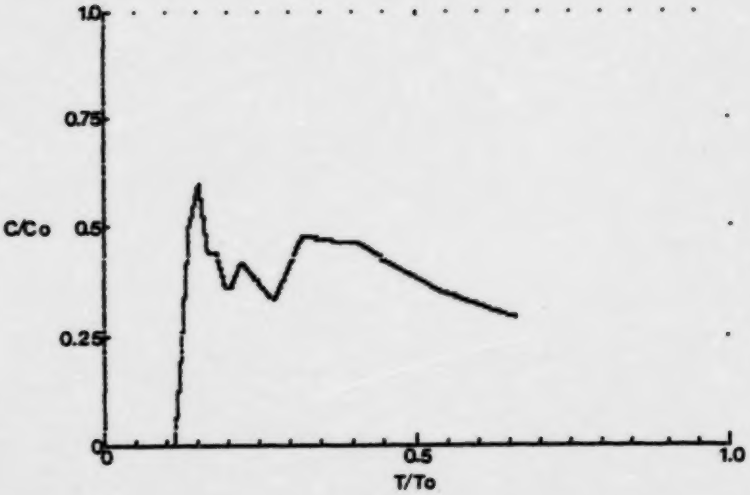


Figure 188. Results of the Multi-Point Dispersion Test of Stamford secondary clarifier #2, weir station D, 19 November 1980.

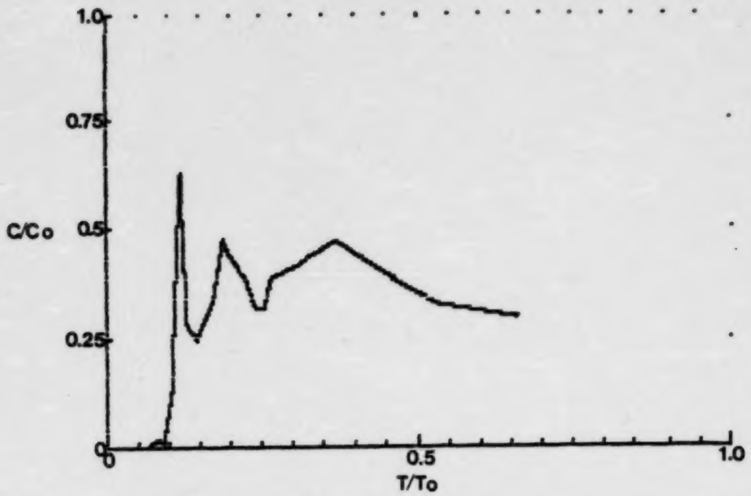


Figure 189. Results of the Multi-Point Dispersion Test of Stamford secondary clarifier #2, weir station E, 19 November 1980.

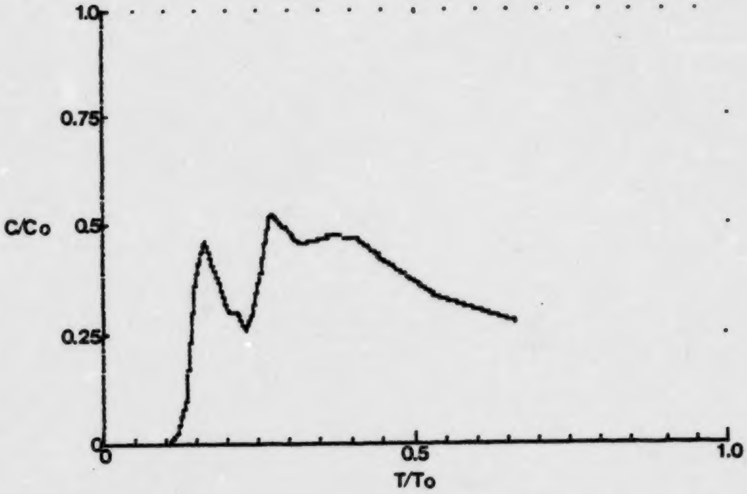


Figure 190. Results of the Multi-Point Dispersion Test of Stamford secondary clarifier #2, weir station F, 19 November 1980.

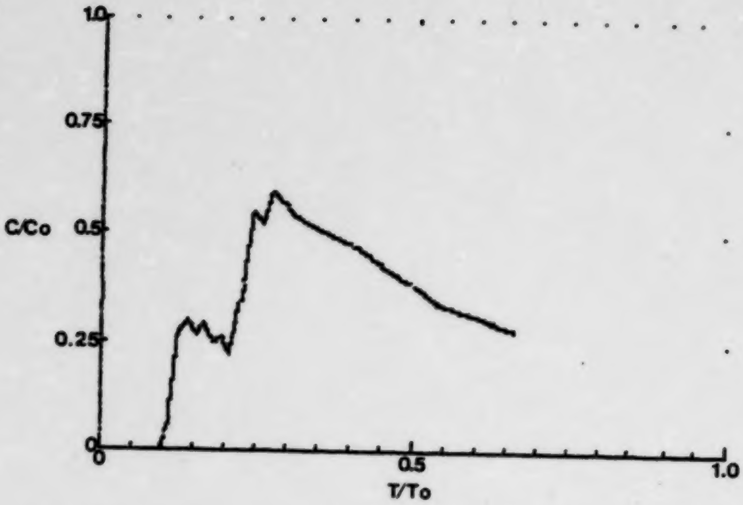


Figure 191. Results of the Multi-Point Dispersion Test of Stamford secondary clarifier #2, weir station G, 19 November 1980.

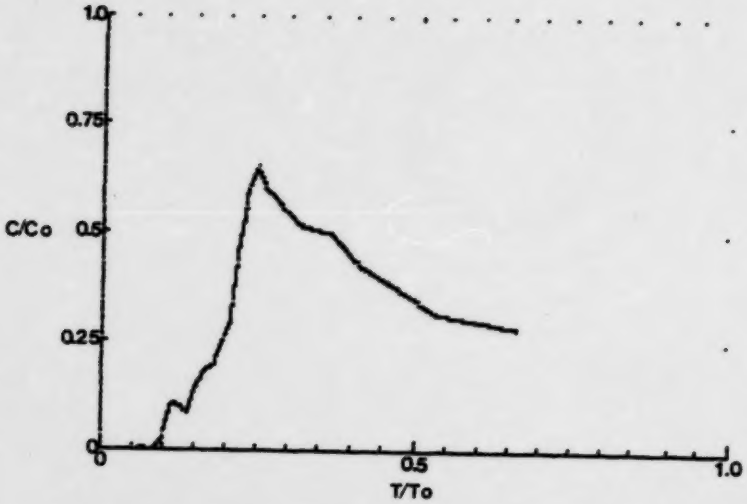


Figure 192. Results of the Multi-Point Dispersion Test of Stamford secondary clarifier #2, weir station H, 19 November 1980.

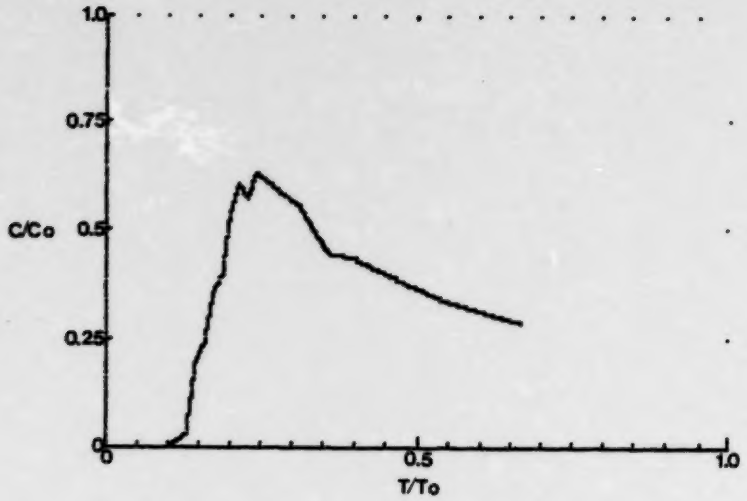


Figure 193. Results of the Multi-Point Dispersion Test of Stamford secondary clarifier #2, weir station I, 19 November 1980.

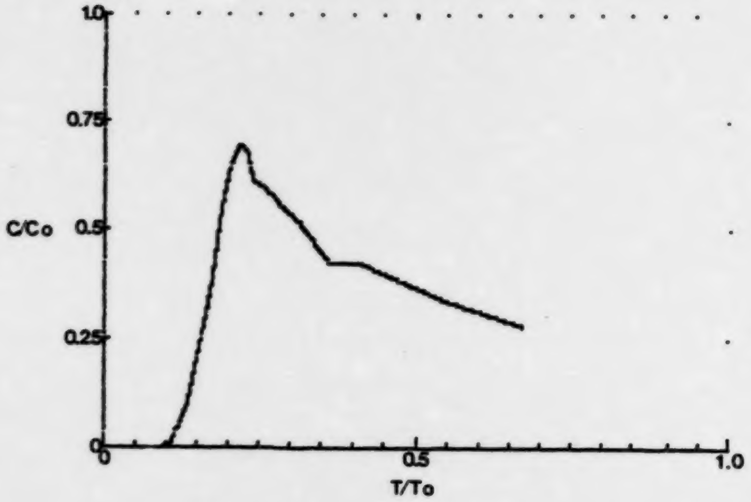


Figure 194. Results of the Multi-Point Dispersion Test of Stamford secondary clarifier #2, weir station J, 19 November 1980.

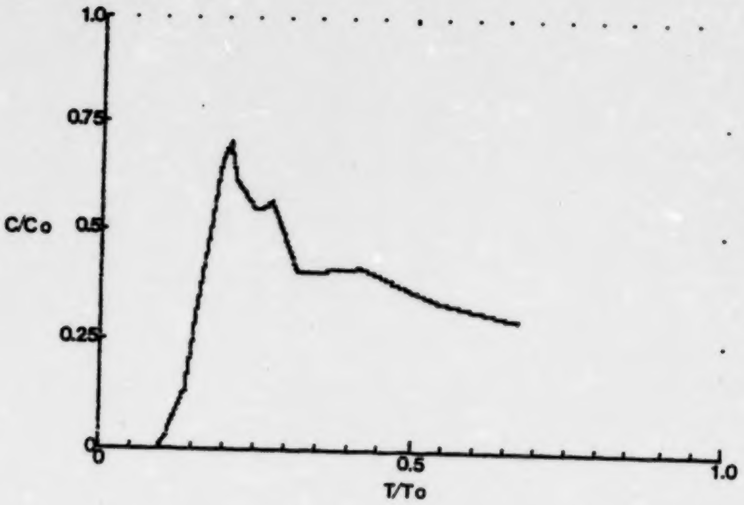


Figure 195. Results of the Multi-Point Dispersion Test of Stamford secondary clarifier #2, weir station K, 19 November 1980.

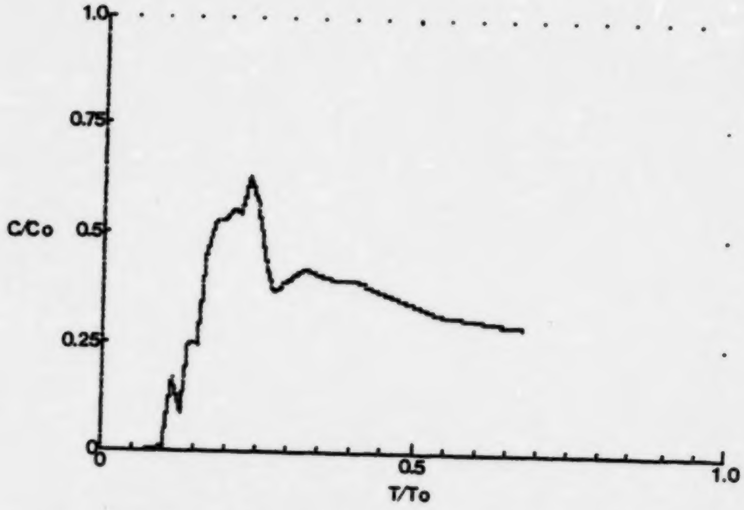


Figure 196. Results of the Multi-Point Dispersion Test of Stamford secondary clarifier #2, weir station L, 19 November 1980.

TABLE 30. DATA PERTINENT TO THE FLOW PATTERN/SOLIDS DISTRIBUTION TESTS ON STAMFORD SECONDARY CLARIFIER #2, 20 NOVEMBER - 8 DECEMBER 1980

Parameter	Unit	Surface Area Overflow Rate				
Surface Area overflow rate	gpd/sq ft	300	600	600	900	1050
Test date		7 Dec. 1980	20 Nov. 1980	6 Dec. 1980	6 Dec. 1980	8 Dec. 1980
Effluent Rate	mgd	3.980	7.960	7.960	11.950	13.940
Underflow Rate	mgd	1.600	1.700	0	2.350	3.500
Depth to blanket	ft	(blanket stripped)	13.0	<11	no sharp interface	no sharp interface
MLTSS	mg/l	3616	3400	812	3052	3444
RASTSS	mg/l	no data	10,620	no return	18,140	19,080
SVI (stirred settling test)		64	68	62	59	49
Mixed liquor inlet temperature	°C	12.9	14.7	no data	12.7	14.0
Effluent temperature	°C	13.1 to 13.2	15.1 to 15.2	no data	12.9 to 13.1	14.0

At 300 gpd/sq ft (12.2 $m^3/m^2 \cdot d$), Figures 197 and 198 show a relatively benign flow regime; the dye has just reached the overflow weir after 43 min. Figure 199 clearly shows that at the minimum practical underflow rate, 1.6 mgd (6000 m^3/d), the blanket is essentially "stripped" from the bottom of the tank.

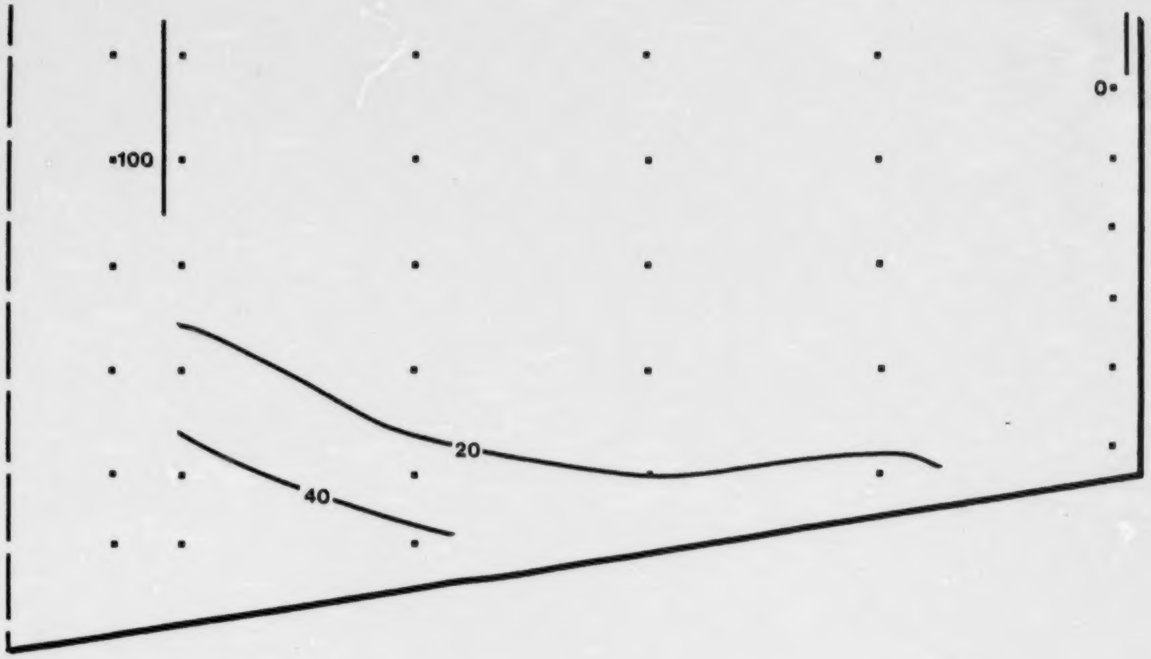


Figure 197. Radial distribution of the dye concentrations in Stamford secondary clarifier #2, 20 min after the start of continuous dye injection, 7 December 1980.

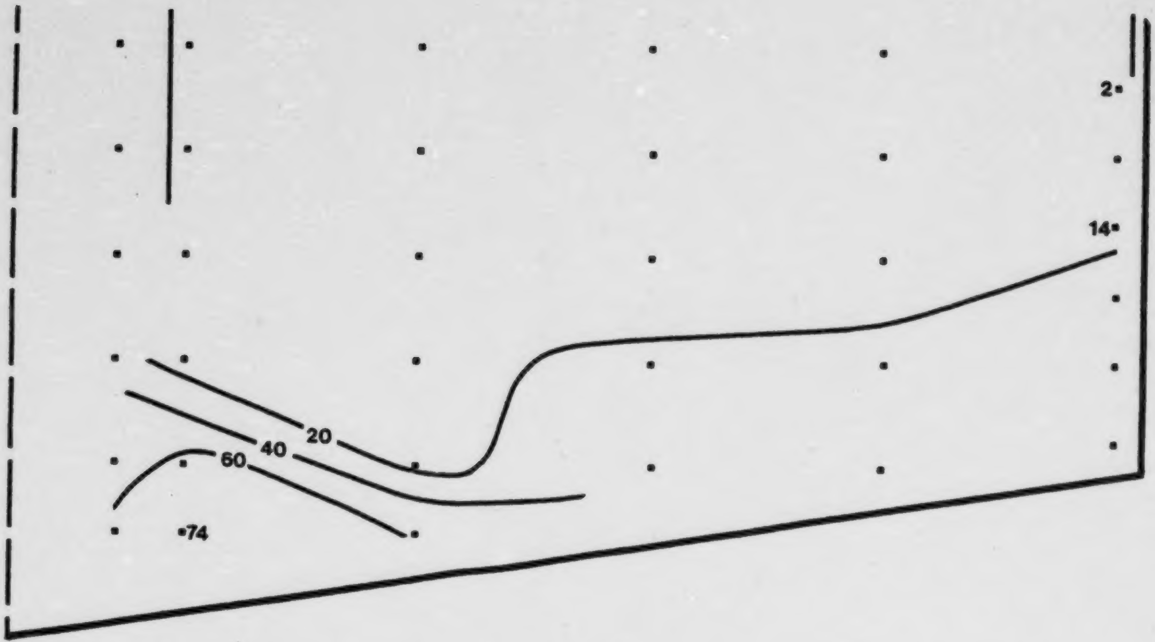


Figure 198. Radial distribution of the dye concentrations in Stamford secondary clarifier #2, 43 min after the start of continuous dye injection, 7 December 1980.

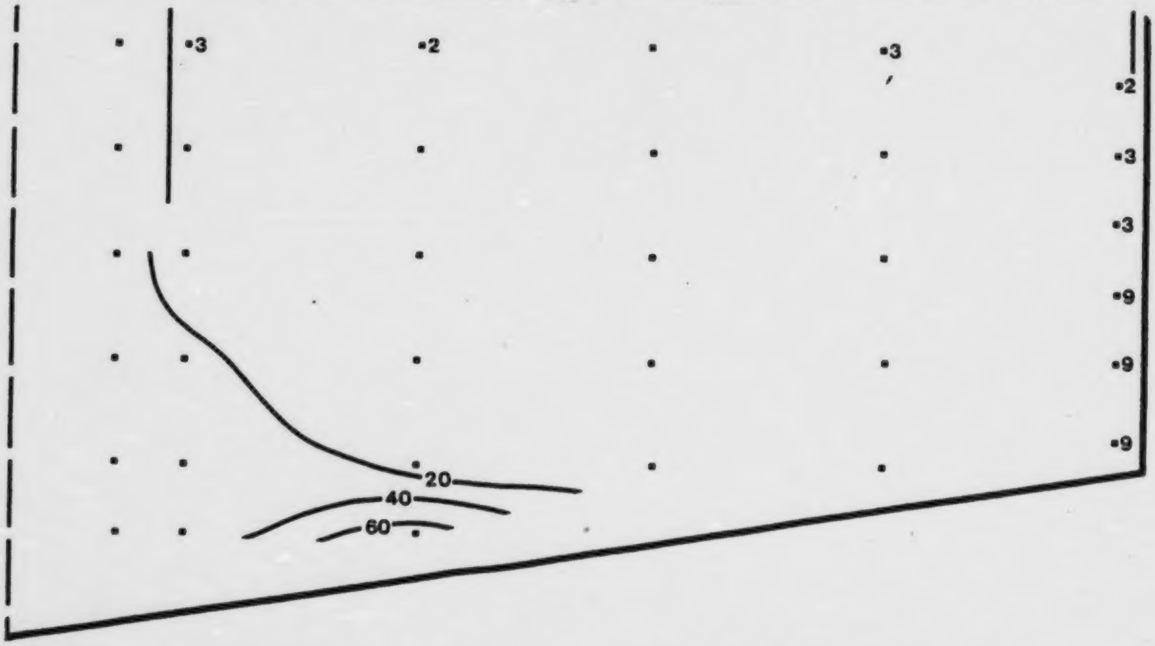


Figure 199. Radial distribution of the square-root of total suspended solids in Stamford secondary clarifier #2, 7 December 1980.

At 600 gpd/sq ft (24.44 $m^3/m^2 \cdot d$), with a normal blanket, there was a slight upflow tendency at mid-radius, most clearly seen in Figure 201. The solids are distributed uniformly, Figure 202.

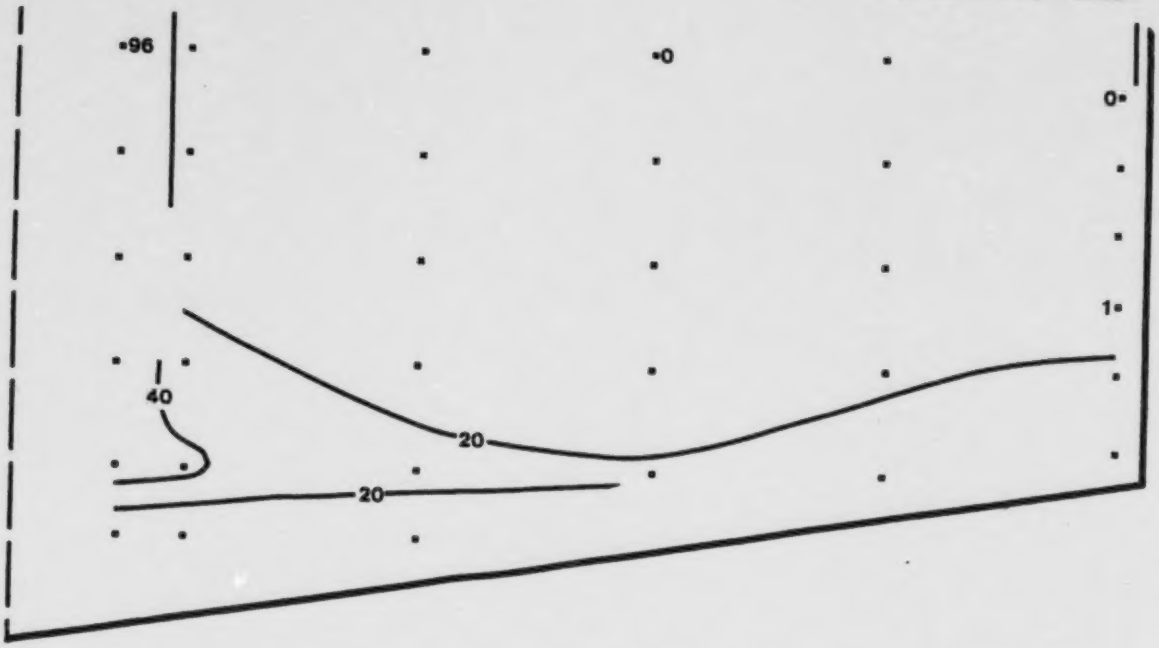


Figure 200. Radial distribution of the dye concentrations in Stamford secondary clarifier #2, 20 min after the start of continuous dye injection, 20 November 1980.

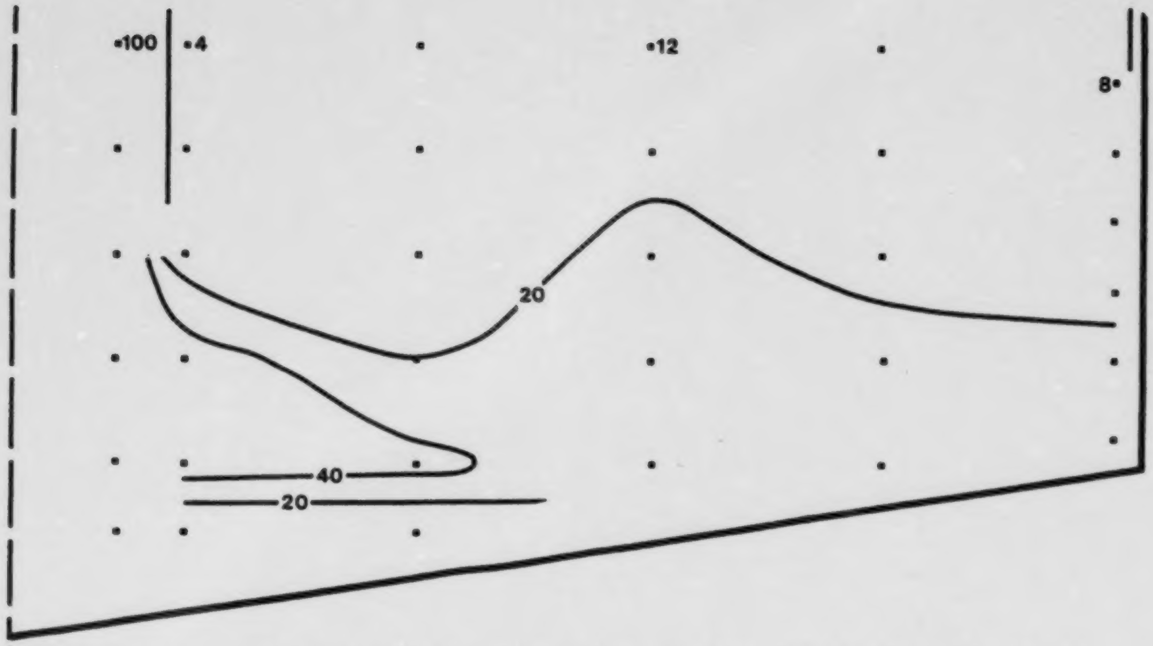


Figure 201. Radial distribution of the dye concentration in Stamford secondary clarifier #2, 43 min after the start of continuous dye injection, 20 November 1980.

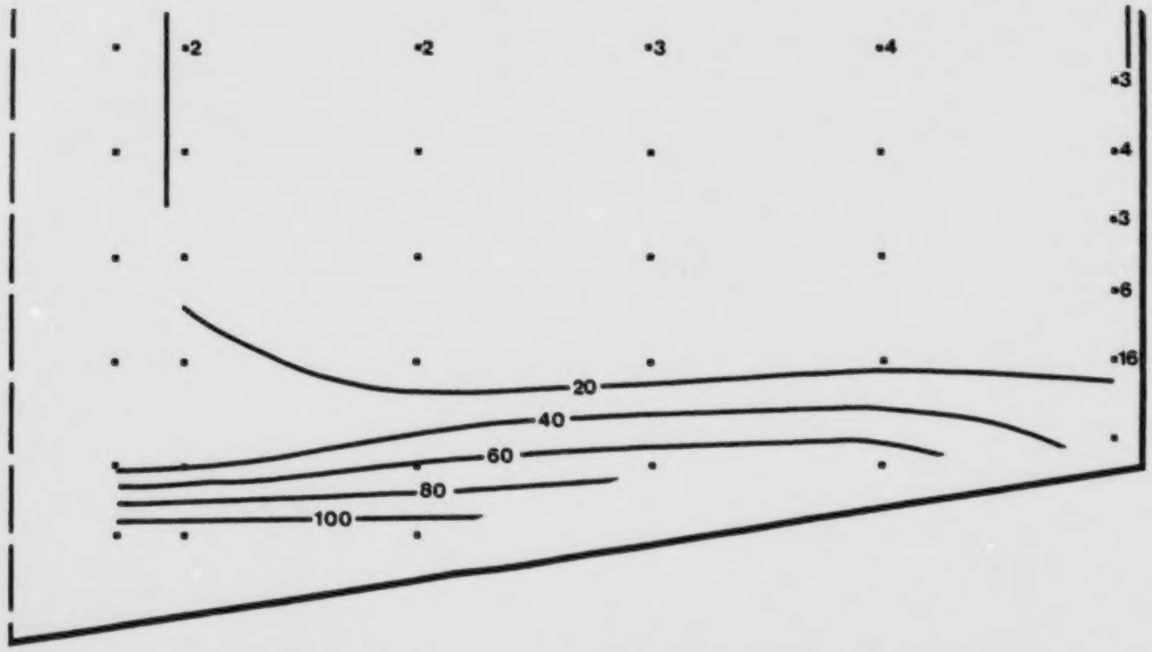


Figure 202. Radial distribution of the square-root of total suspended solids in Stamford secondary clarifier #2, 20 November 1980.

At 600 gpd/sq ft (24.44 $m^3/m^2 \cdot d$) with a high blanket, the "football shaped" contours, Figures 203 and 204, suggest a turbulent flow regime, with relatively high concentrations of dye reaching the overflow weirs quickly. The reason, it is believed, can be seen in Figure 205. The high blanket has approached the lower edge of the feedwell; the area through which the influent must pass as it enters the tank is restricted. Suspended solids concentrations on the peripheral wall are high. It should be noted that the mixed liquor total suspended solids concentration was low, 812 mg/l. A majority of the plant's solids inventory was in clarifier #2 in an effort to achieve a high blanket test condition, an experimental misjudgement on the part of the principal investigator.

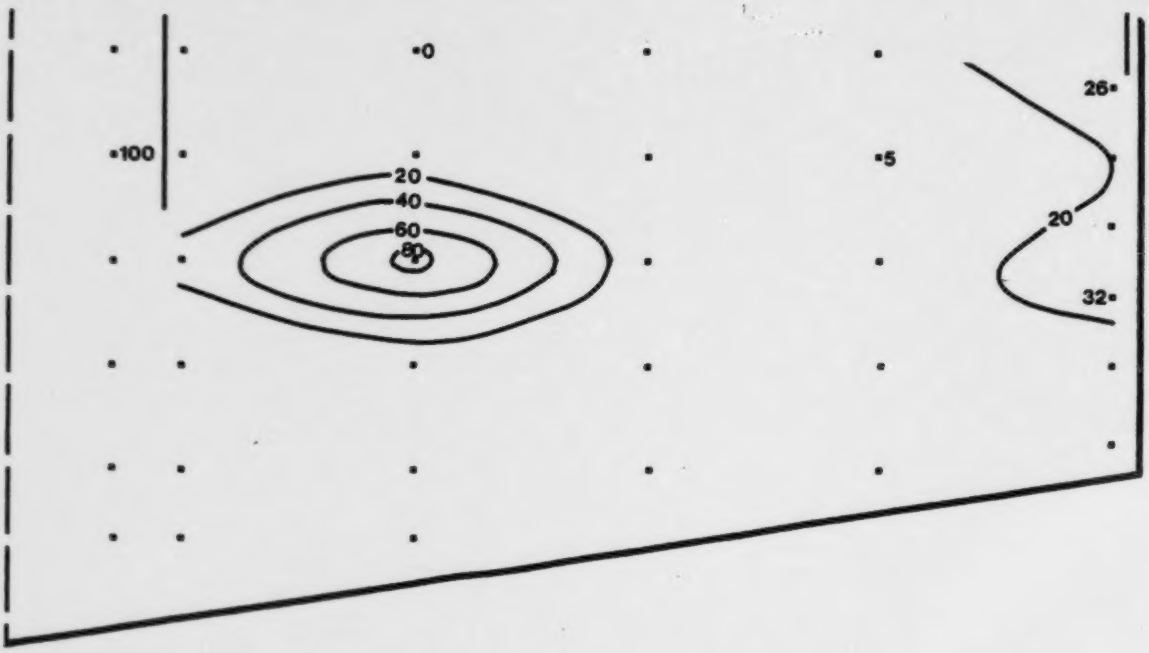


Figure 203. Radial distribution of the dye concentrations in Stamford secondary clarifier #2, 20 min after the start of continuous dye injection, 21 November 1980.

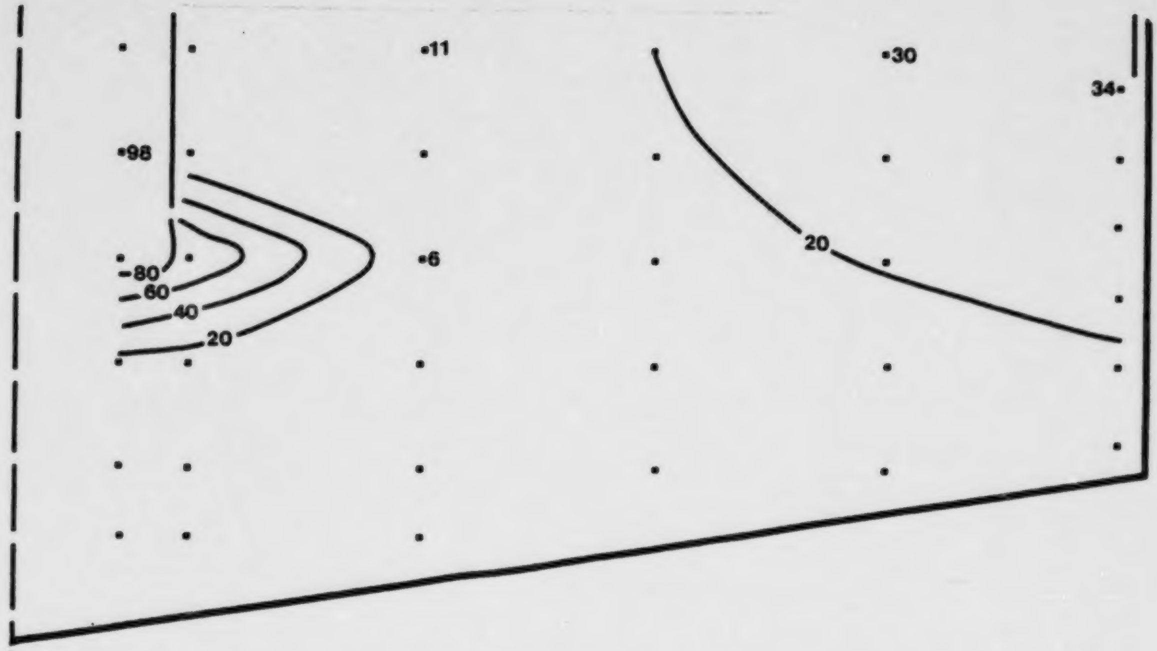


Figure 204. Radial distribution of the dye concentrations in Stamford secondary clarifier #2, 43 min after the start of continuous dye injection, 21 November 1980.

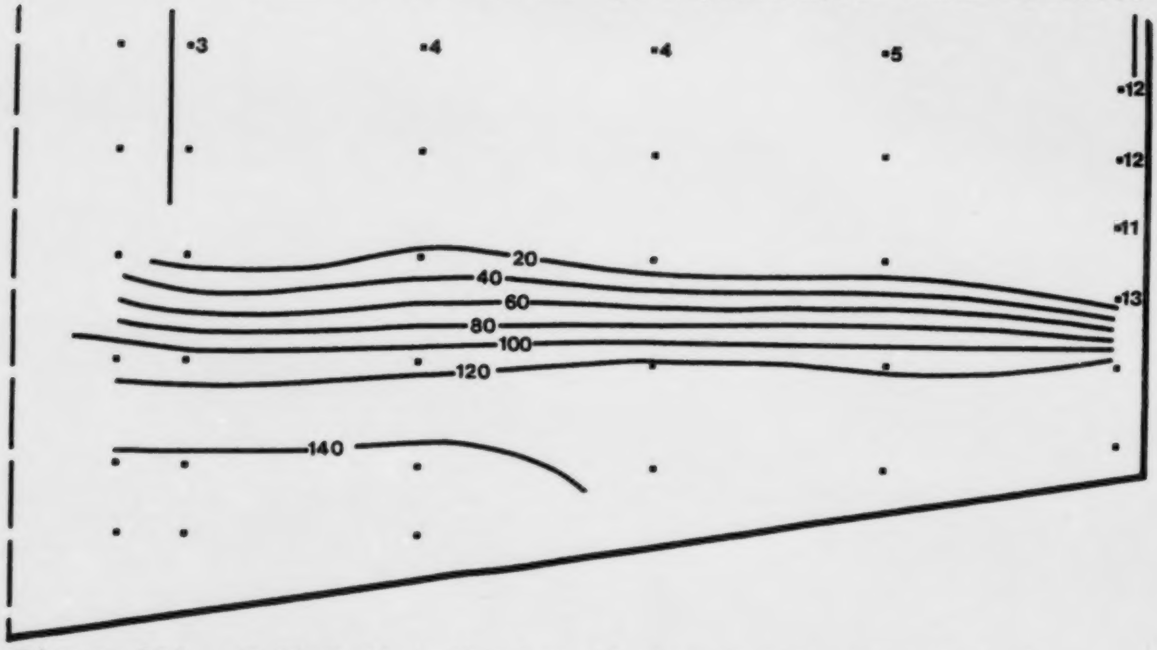


Figure 205. Radial distribution of the square-root of total suspended solids in Stamford secondary clarifier #2, 21 November 1980.

Early stages of hydraulic stress became apparent during the 900 gpd/sq ft (36.66 $m^3/m^2\cdot d$) test. Significant dye concentrations overflowed the weirs after 43 min, Figure 207. Although effluent total suspended solids were low, Figure 208, the blanket was diffuse, with no clearly definable interface. Most intense horizontal flow occurred at a depth at which solids concentrations ranged from 3600-6400 mg/l. In light of the Flow Pattern/Solids Distribution Test results presented earlier in this report, horizontal flow at this depth, and at these concentrations is surprising.

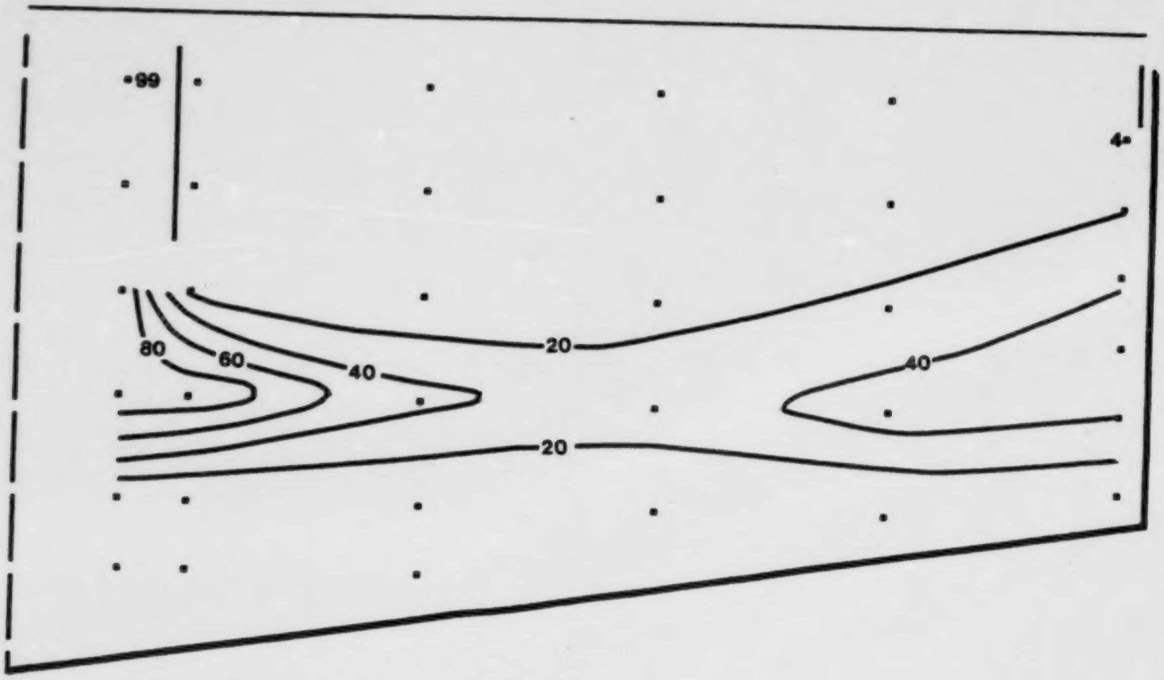


Figure 206. Radial distribution of the dye concentrations in Stamford secondary clarifier #2, 20 min after the start of continuous dye injection, 6 December 1980.

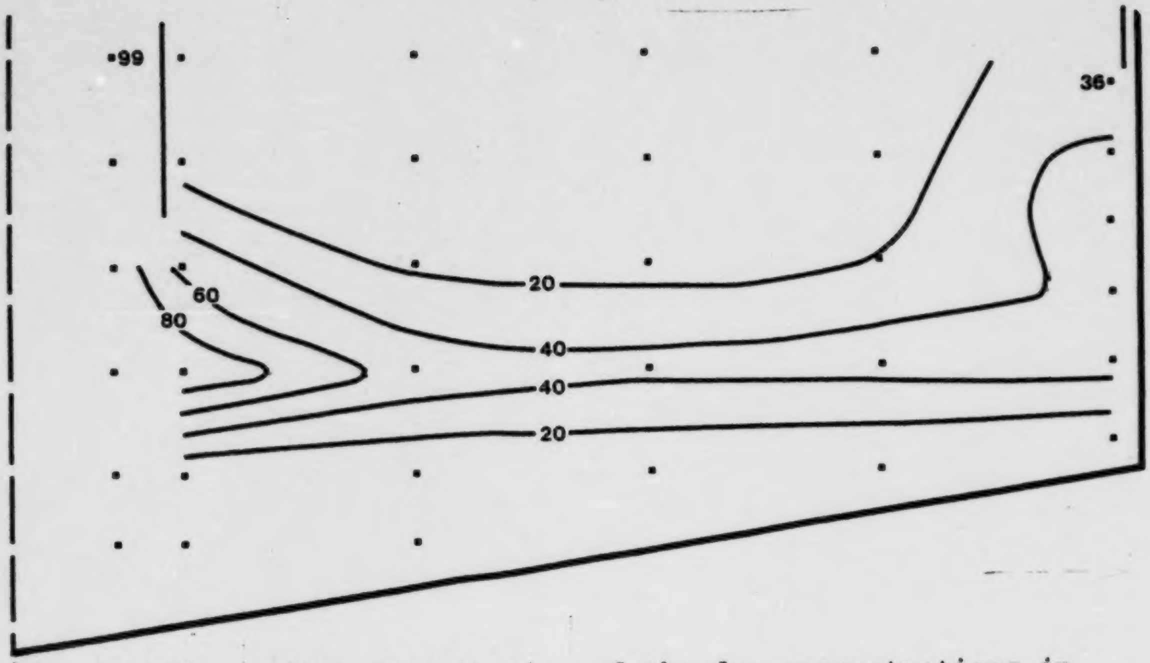


Figure 207. Radial distribution of the dye concentrations in Stamford secondary clarifier #2, 43 min after the start of continuous dye injection, 6 December 1980.

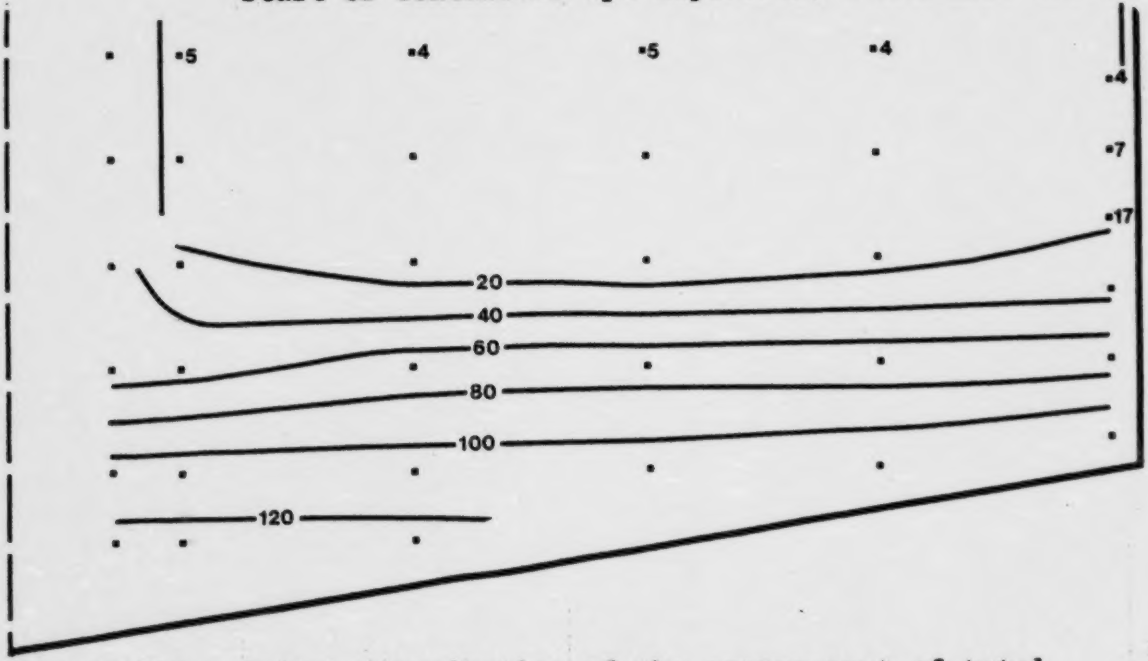


Figure 208. Radial distribution of the square-root of total suspended solids in Stamford secondary clarifier #2, 6 December 1980.

Similar results were obtained in the test at 1050 gpd/sq ft ($42.8\ m^3/m^2 \cdot d$). Figure 209 suggests a relatively intense downflow at the feedwell. Figure 210 shows that horizontal flow, between the 40 ppb contours, results in peripheral wall upflow and recirculation toward the central backeddy region. In Figure 211, the solids are again relatively diffuse; most intense horizontal flow has occurred within solids concentrations which range from 1600-3600 mg/l.

Additional observations during this test series concern changes in dissolved oxygen concentrations and diurnal changes in mixed liquor (inlet) and effluent temperatures:

- Vertical profiles of dissolved oxygen concentrations at mid radius in secondary clarifier #2 showed an absence of oxygen in the tank. Dissolved oxygen concentrations were subsequently measured at several locations between the aeration basins and the clarifier point of discharge. Trials on several days showed a gradual decrease in oxygen concentration from 2-3 mg/l near the aeration basins to less than 1 mg/l in the clarifier's feedwell. Within the clarifier itself, no dissolved oxygen was detected. In the effluent launders, dissolved oxygen concentration increased to about 2 mg/l; reoxygenation apparently occurred as the effluent spilled over the weirs.

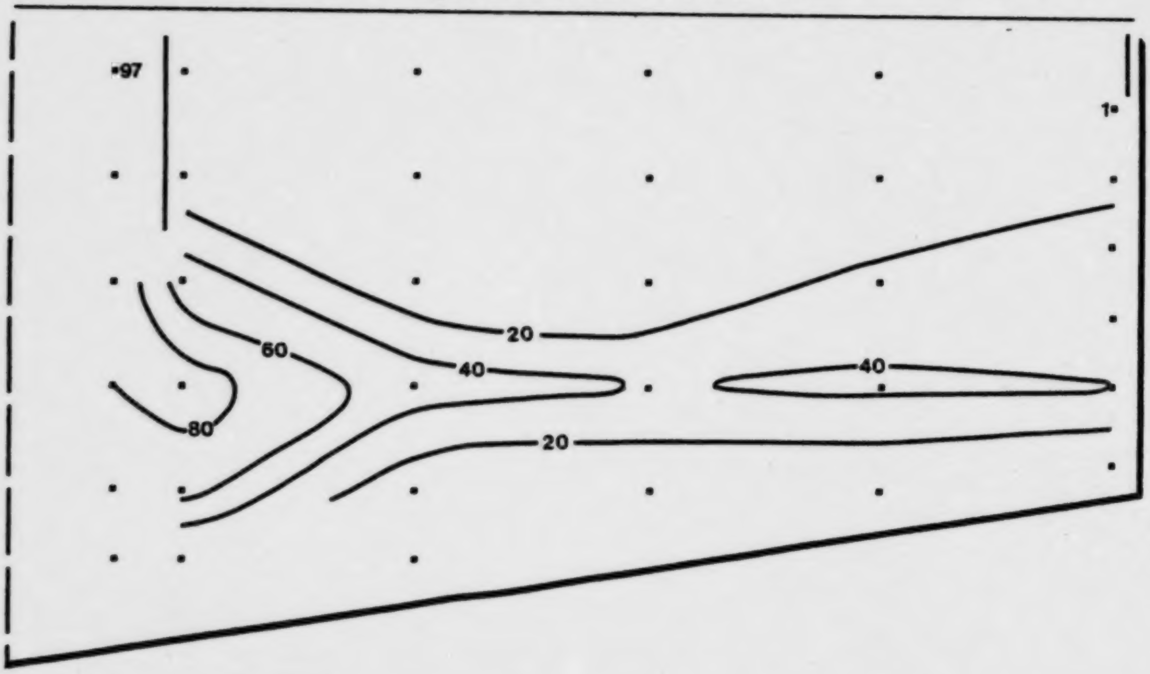


Figure 209. Radial distribution of the dye concentrations in Stamford secondary clarifier #2, 20 min after the start of continuous dye injection, 8 December 1980.

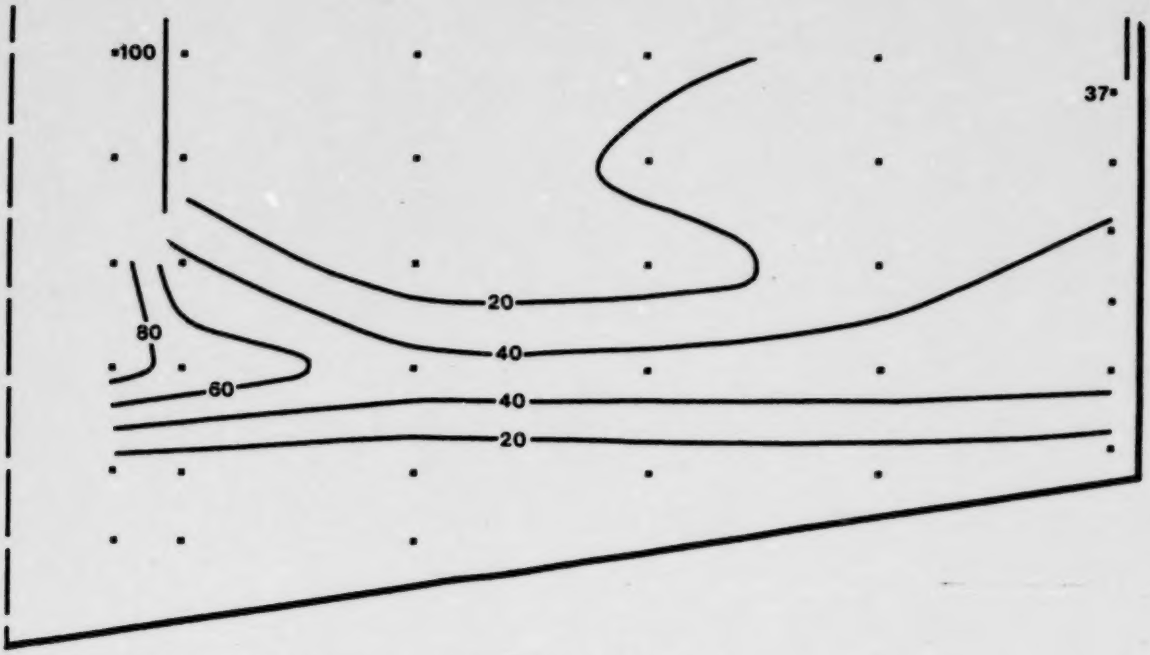


Figure 210. Radial distribution of the dye concentrations in Stamford secondary clarifier #2, 43 min after the start of continuous dye injection, 8 December 1980.

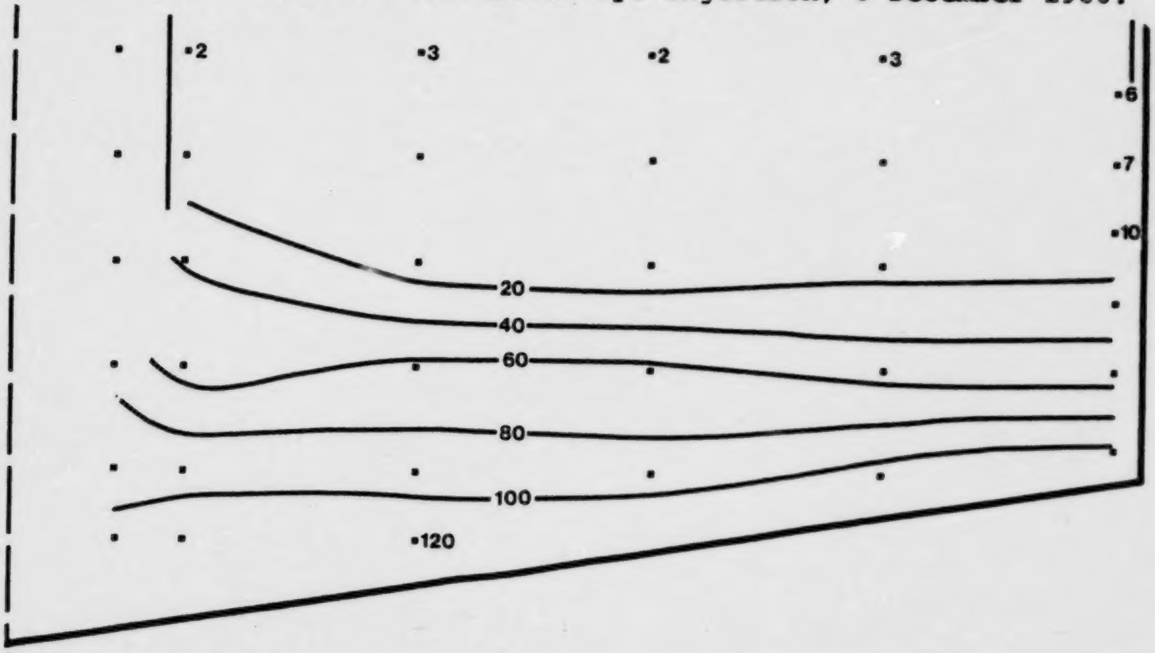


Figure 211. Radial distribution of the square-root of total suspended solids in Stamford secondary clarifier #2, 8 December 1980.

- Inlet temperature exhibited a diurnal change of the order of 1.0 to 1.5°C peak to peak. Similarly, the effluent temperature was typically 0.2 to 0.4°C cooler than the inlet temperature at night and 0.2 to 0.6°C warmer in the daytime. This is believed to be due to gradual entrainment of surface "backeddy" water. The implications of this phenomenon on the physical behavior of the fluid in the clarifier or on effluent quality have not been determined. A nearly continuous record of inlet temperature and inlet/effluent differential temperature was recorded through August 1981, but the data have not been analyzed.

SECTION 6

FACTORS AFFECTING CLARIFIER DESIGN AND OPERATION

GENERAL

A large amount of data related to clarifier hydraulic characteristics and performance have been presented in the preceeding section of this report. The purpose of this section is to further analyze this data and present a more complete, if not entirely defensible explanation of the factors thought to control clarifier operation and performance.

During the early stages of this project it became apparent that the factors controlling clarifier hydraulic characteristics and performance were numerous and complex. This meant the project would not provide all of the answers. But it was hoped that the study would define the problems more precisely. The reader is cautioned that even though a large amount of data was collected, all conclusions presented in this section are not completely documented and thus should be considered to represent mainly the philosophy of the author.

Major conclusions reached by the author include the following:

- In many cases, better effluent quality can be achieved in existing facilities without major construction to add what is traditionally termed "more clarifier hydraulic capacity". In terms of existing engineering design standards, one of which will be discussed in this section, this usually means additional clarifiers.

- Equivalent effluent quality can be achieved at lower capital improvement and/or operating costs by settling tank designs which place less emphasis on empirically derived and non-specific design standards and greater emphasis on actual efficiency of clarification, i.e., performance standards. It is really quite easy to improve the clarification efficiency of many existing units. It should be equally easy, and less costly, to build smaller units with improvements already in place.

Presently, this investigator's key to discovery of ways to improve clarifiers is a series of detailed measurements to identify the reasons for unsatisfactory performance. The utility of such measurements has been demonstrated. The second step in the improvement procedure is application of a "sense of fluid behavior" to the measurements and observations, to devise ways to keep the unsettled part of the floc as far from the discharge as possible. The clarifier designer or modifier needs to start "thinking like water" rather than approaching design as a rote procedure.

The effectiveness of 3 kinds of baffles, a storage scheme and a riser pipe mechanism speed change have been evaluated. All were successful to some extent. The applicability of these modifications to other treatment plants is unknown. From the data presented, it could be seen that the effectiveness of the changes will depend on the characteristics of the mixed liquor, on the details of the clarifier structure and, probably, on the steadiness or variability of flows.

For the most part, this section is intended to relate this study's results to hydraulic theory, to discuss measured performance-affecting factors which seem applicable to many existing clarifiers and to set down fluid-motion related algebraic relationships which might help to explain some phenomena which could affect clarifier performance A preliminary Solids Transport Model will also be introduced.

SETTLING THEORY, DESIGN STANDARDS AND REAL CLARIFIERS

In 1945, Thomas R. Camp[6] presented a concise description of an ideal settling tank, based largely on earlier work by Hazen.[8] Essentially, Camp's paper stated that the removal of suspended matter depends on surface area and not on tank volume. He derived a term, "overflow rate", v_o, which has become a widely accepted theoretical basis for clarifier design:

$$v_o = \frac{Q}{A}$$

where: v_o = that settling velocity which must be achieved by all particles which will settle out
Q = the rate of discharge of the clarifier
A = the surface area of the tank

One possible model is uniform flow upward, over the entire surface of the tank. In this study, this theoretical model was nearly achieved in the Oakland, CA, EBMUD peripheral feed, peripheral overflow secondary, at design flow rate, with a normal blanket. The dye test series on EBMUD secondary clarifier #11, 5 February 1979, is presented differently in Figure 212. The 40 ppb contour had just reached 1 ft (0.3 m) below the surface, at sampling station 2, in 105 min. The time progression of 40 ppb dye contour lines from the "snapshot" at 40, 70 and 105 min is shown. Clearly, there is a gradual, and fairly uniform tendency for upflow.

A second possible model is uniform horizontal flow, commonly called plug-flow. This effect was nearly achieved at the weir end of the Orange County, FL, Sand Lake Road plant secondary clarifier #1, under 133% of design overflow rate conditions, 20 September 1979, Figure 134.

A review of all flow pattern data in this study will show no other case in which the theoretical ideal throughflow regime was even approximated.

Scant guidance is given to the facility designer by at least one set of widely accepted design standards[7], usually referred to as the "Ten State Standards".

- On tank configuration: "Consideration should be given to the probable flow pattern in the selection of tank size and shape, and inlet and outlet type and location."
- On inlet structures: "Inlets should be designed to dissipate the inlet velocity, to distribute the flow equally both horizontally and vertically and to prevent short circuiting. Channels should..."
- On weir location: "Overflow weirs shall be located to optimize actual hydraulic detention time, and minimize short circuiting."

Further, maximum surface area overflow rates are stated for various activated sludge processes. Essentially, that's all.

With the completion of this study, "...probable flow pattern..." can now be translated into something more tangible, at least for the cases studied. It can also be seen that inlets

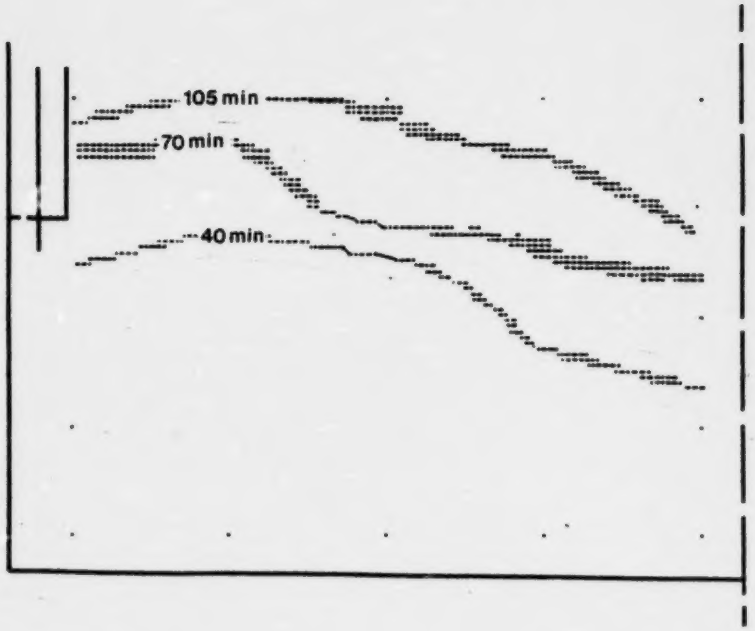


Figure 212. Time progression of the 40 ppb dye contour from the Flow Pattern/Solids Distribution Test on EBMUD secondary clarifier #11, 5 February 1979.

are not designed to "...distribute flow equally both horizontally and vertically... ." Instead, downflow is encouraged. It is also obvious, in many cases, that overflow weirs are placed directly in the path of highest upward flow velocities, where unsettled floc particles are likely to be entrained and swept to the discharge. In center feed, peripheral overflow circular clarifiers, the selection of weir location may result from a combination of factors:

1. Design standards specify maximum "weir loading rates", typically 10000-15000 gpd/ft (124-186 $m^3/m \cdot d$)[7]. This standard can be satisfied by placing the overflow weirs at the periphery of a circular tank of large enough diameter. (The designer must also satisfy the surface area overflow rate standard.)

2. Peripheral weirs cost less than multiple ranks of weirs, such as those at Albuquerque.

3. Scum removal is facilitated by placing weirs at the periphery only.

It is apparent from this study's data that "short circuiting" is the rule, not the exception. Although the principal investigator has offerred no firm evidence to support the statement, it is intuitively sensed that the factor which most actively controls the solids-transporting throughflow pathway is inlet-induced fluid momentum rather than "suction" from the weirs.

A second widely utilized design model involves Flux Theory[9]. This viewpoint considers that one main role of secondary clarifiers is sludge thickening. Application of the theory involves the assumption of uniform solids distribution over the tank's projected area. In practice, solids are seldom uniformly distributed. Achievement of adequate or desired underflow solids concentrations may, in practice, involve the risk of attaining a blanket height which approaches the lower extremity of the inlet baffle, which apparently results in excessive horizontal throughflow velocities and energetic eddy turbulence. In the case of abnormally slow settling, or bulking sludges, the blanket may rise to near the surface, with a risk of very high effluent suspended solids concentrations, usually referred to as carryover, especially in plants where flows are unsteady.

THE SLUDGE BLANKET

Blanket Definition

Heretofore, the term "sludge blanket" has been used "loosely" in this report. However, there is no universally accepted definition for the term. In waste treatment plant operation, the blanket position may be "defined" by the appearance of a more-or-less sharp interface visible in a "core sample" of the water column trapped in a length of transparent plastic tubing. Other common methods of blanket finding include soundings with various optical or sonic sensors, the outputs of which change noticeably at a depth at which fluid turbidity reaches a certain unspecified value. Usually, blanket position determinations are made at mid-radius of circular tanks or near the center of rectangular tanks. In theoretical discussions, a fixed solids concentration of 2000 mg/l is often quoted as the top-of-blanket concentration. This study has shown that solids are not generally uniformly distributed horizontally.

In every Flow Pattern/Solids Distribution Test case presented, a zone of horizontal flow existed. Horizontal flow occurred within a wide range of solids concentrations, perhaps 400-4000 mg/l. Because throughflow is occurring, compaction is not complete; the zone is fluid. Below this horizontal flow zone, an effective hydraulic barrier exists. With this uncertainty of terminology in mind, and for want of a better definition, the investigator considers that the blanket exists just beneath the depth of highest velocity horizontal flow.

Hydraulic Behavior Related to Sludge Quality

At Albuquerque, NM, a slow-settling sludge resulted in a thick, but slow-moving layer of horizontal throughflow. Effluent quality was very good. In the initial studies on Stamford secondary clarifier #1, with what is normally considered to be a good quality air activated sludge, a moderate-thickness horizontal flow zone existed. Effluent quality was fair. In the initial studies on Morganton's secondary clarifier #1, sludge was considered to be of good quality for oxygen activated sludge. The horizontal flow zone was very thin; horizontal velocity was obviously high; effluent quality was poor.

In these three inadequately documented examples, the effluent suspended solids concentrations of the unmodified clarifier seem to be inversely related to SVI. However, in the comparative tests, correlations between SVI and effluent TSS are not good at each site. Similarly, the plant-to-plant comparisons of effluent quality and SVI are apparently in the "wrong direction". Thus, as a practical tool for operator control of secondary clarifier effluent quality, the utility of the SVI calculation is questioned.

This investigator knows of no process control parameter which is directly related, in a significant way, to the performance of secondary clarifiers. It is "common knowledge" that very rapid settling sludges often fail to produce a clear effluent because fine particles of unconsolidated floc are left behind in association with high settling velocities. Conversely, "common knowledge" also holds that bulking sludges with moderately high relative populations of filamentous organisms can result in effluent of extremely low turbidity, if the sludge can be separated and blanket level controlled.

These remarks point out the inadequacy of control strategies useable at the operator level. They also reinforce this investigators contention that many secondary clarifiers in common use do not optimally serve the operator's need for controlled, good effluent quality. The operator's control strategies must be empirically developed for his facility.

At What Depth Should the Blanket Be?

Figure 213, the distribution of solids at mid-radius at Stamford, CT, leads the reader to wonder whether depth-to-blanket, or blanket thickness can be estimated as a day-to-day practical process control parameter. The illustration clearly shows that one "blanket finding" does not necessarily represent the depth to an "interface" over the entire area of the clarifier. Numerous other illustrations of radial or longitudinal solids distributions in Section 6 of this report lead to the same conclusion. But these examples are merely details, with exaggerated vertical scales, which cannot concern the operator; he has neither the time nor the equipment for such detailed determinations.

At the Dallas County, TX, Ten Mile Creek plant, consistently low values of effluent TSS are achieved by maintaining a very low blanket. At Albuquerque, NM, good effluent quality was also seen with a relatively high, but vertically stable blanket. In observations of a chemical plant's activated sludge secondary[2] and the secondaries in a municipal plant[3], the sludge blanket could be clearly observed several feet below the water surface, through exceptionally clear supernate. At Albuquerque and at the other two plants cited, the lower edge of the central feedwell was beneath the perceived solids/supernate interface.

At Stamford, CT, on 21 November 1980, the Flow Pattern/Solids Distribution Test showed that the blanket lay just under the feedwell's lower rim, Figure 214. Flow was excessively turbulent; peripheral wall solids concentrations were high. Admittedly, the 21 November 1980 Stamford test series was conducted under abnormally low mixed liquor solids concentration conditions. But the same phenomenon has been observed elsewhere.[4] Flow was also excessively turbulent in EBMUD secondary #11 under a high blanket condition.

Although these examples do not constitute proof, it is reasonable to expect that high velocity and energetic eddy turbulence will result from flow through a constricted "orifice" of this kind.

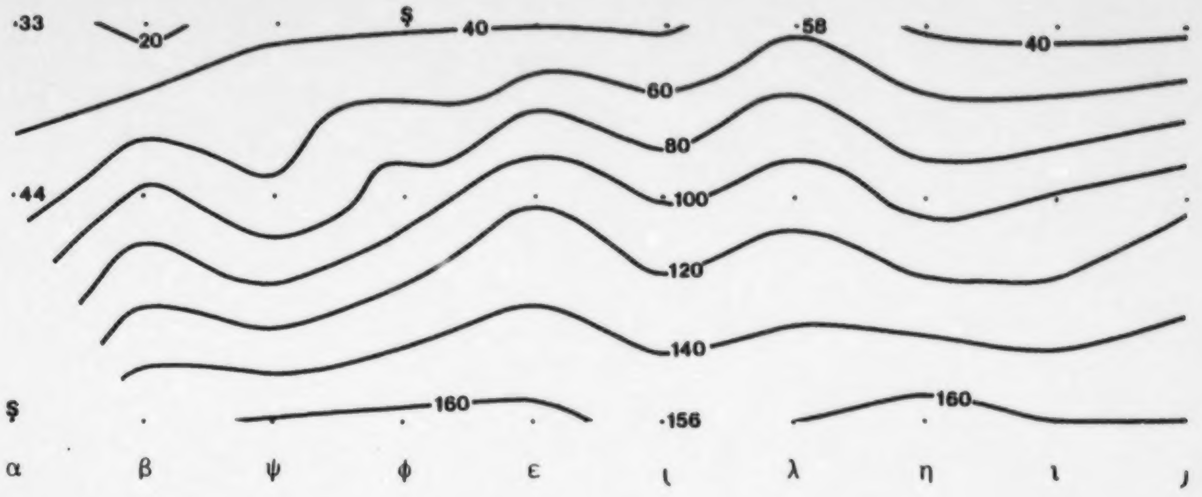


Figure 213. Distribution of the square-root of total suspended solids in the mid-radius section, Stamford secondary clarifier #2, 23 October 1980. The section illustrates variability of concentrations with direction and depth.

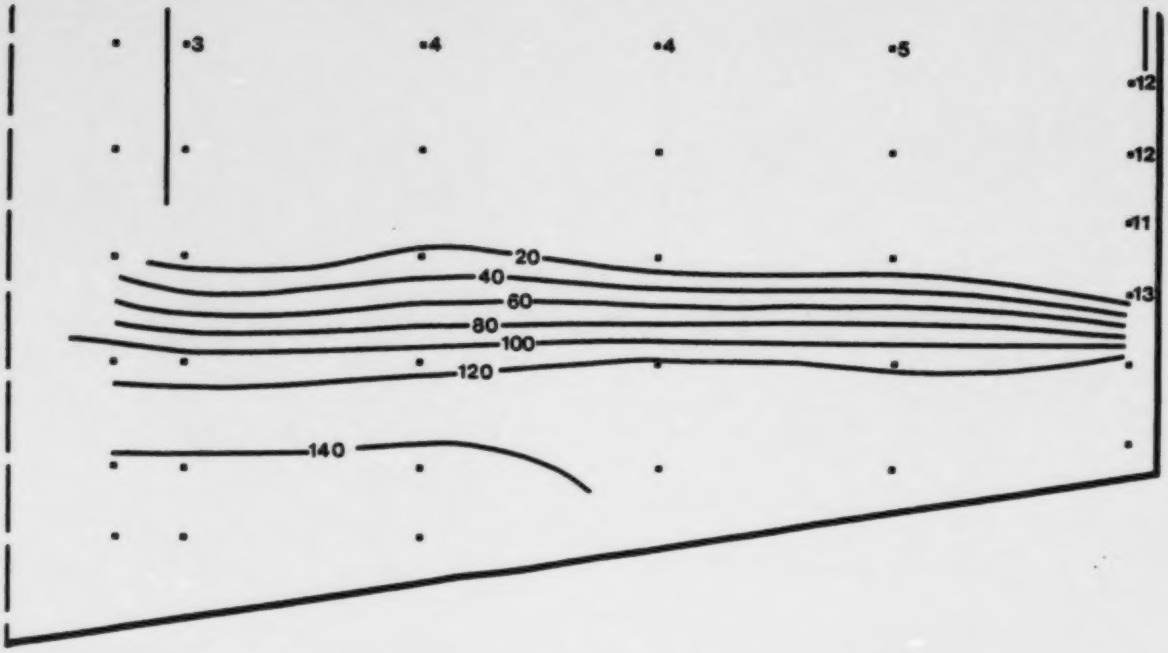


Figure 214. Radial distribution of the square-root of total suspended solids in Stamford secondary clarifier #2, 21 November 1980.

Based on this investigator's observations and measurements, the following opinions are offered:

1. If sludge settleability is poor, flow rates are reasonably steady and the half-of-tank-depth feedwell configuration is available, the operator should try to maintain a high blanket, with the lower extremity of the feedwell below the solids/supernate interface. If the blanket cannot be controlled at this depth, the alternative is to increase underflow rate so that the interface is several feet below the feedwell.

2. If sludge settleability is considered good, the underflow rate should be maintained at the minimum value which assures adequate clearance between the feedwell and the solids/supernate interface. An underflow rate which is unnecessarily high will increase the tank influent rate, creating un-needed turbulence such as was seen in the Dallas County Ten Mile Creek secondary's solids distribution.

3. Never allow the blanket to reside very near the depth of the lower extremity of the inlet baffle, or feedwell. In other words, a high blanket or low blanket may be acceptable, under the appropriate conditions. A moderate blanket depth should be avoided.

SLUDGE JETS

Many clarifiers have relatively few, discrete inlet ports from which coherent streams of slurry enter the tanks. A density current develops as a result of the slightly higher specific gravity of the mixed liquor with respect to the specific gravity of the supernate. These density currents persist as discrete jets, frequently to the weir wall. These jets constitute "short-circuits" in the horizontal plane, with slower moving fluid between the jets. This phenomenon has even been observed in a center feed, peripheral overflow secondary with approximately 48 discrete inlet slots [10,11].

At Stamford, CT, the inlet jets were intermittently interrupted, or partially dispersed, as the vertical portions of the riser pipes passed in front of the inlet ports. The jet effect, at Stamford, is clearly illustrated in Figure 215. It can be assumed that these same solids peaks occur and recur at 4 weir regions. The deleterious effect on effluent quality can only be estimated with the Weir-Wall Solids Test data at hand. However, if it is assumed that the primary effect of the peripheral baffle at Stamford was to interrupt the jet effect, then destruction of the jet effect decreased effluent TSS by about 38%. Within the bounds of confidence expressed by this report's data, the principal investigator is convinced that the basic design of the Stamford type inlet configuration is less than ideal. Feedwell diameter design procedures based on downflow velocity seem absurd in light of the uneven velocity distribution implied in the Stamford jet data.

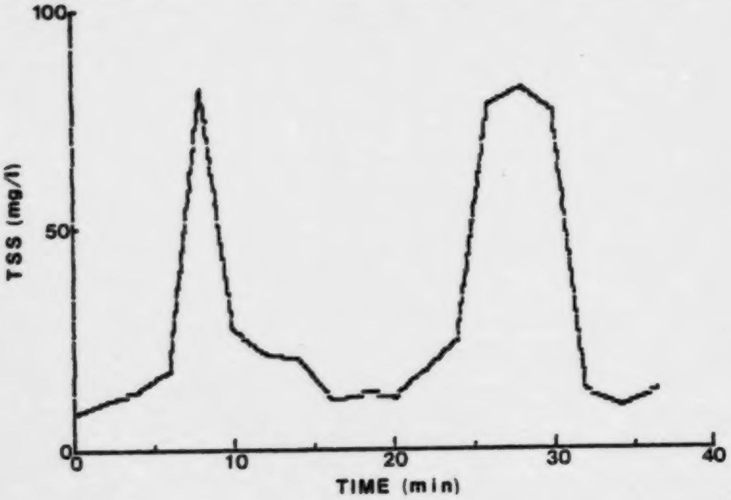


Figure 215. Weir-Wall Solids Test result at Stamford, CT, 3.75 ft (1.143 m) below the overflow weir, 6 August 1979.

SLUDGE HEADER PROBLEMS OBSERVED

This discussion only concerns the general class of sludge removal mechanisms which include riser pipes, single tube headers and traveling bridges. Those mechanisms which simply rake sludge to a central sump were not examined in this study. Thus, the following is a one-sided view which cannot address the relative merits of the rake and the header.

The reasoning process by which an equipment manufacturer arrives at a specific design is not public information. Certainly, his concerns include return of the sludge before excessive mortality of useful microorganisms can occur. It is considered important by some to return a sludge of adequate thickness, which facilitates dewatering of the waste sludge fraction. Structural cost and equipment reliability are also factors.

Uniformity of removal, with respect to sludge thickness and volume per unit time, or flow rate, seem to be the most difficult goals to achieve. For example, from theoretical considerations, in which settled solids are uniformly distributed on the bottom of a tank, it would seem reasonable to try to achieve a greater underflow rate from the periphery of a circular tank; the outer half of a radial header's sweep must remove sludge from 4 times the area of the inner half-radius. But at Morganton, Figure 68, solids concentrations were much higher near the tank periphery in the test section. Under abnormal flow conditions in Oakland's secondary #11, Figure 118, high concentrations existed near one side of the test section. Under more normal conditions in the same tank, Figures 92 and 103 showed relatively low concentrations near the periphery. In several observations at Stamford, Figures 152, 169, 199 and 202, center-of-tank solids concentrations were significantly higher than at the periphery. At Albuquerque, Figure 14 shows that mid-radius riser pipes are more active than central or peripheral ones. If the goal of maximum underflow concentration is to be met, operators need to abandon simplistic rules-of-thumb in setting individual riser pipe return rates in favor of observations of the relative "thickness" of the flow from individual risers.

Unfortunately, the problem is not always that simple. The investigator has frequently observed zero return flow from as many as 50% of a clarifier's riser pipes at a given time. At Morganton, a home-made "plumber's friend", devised from a rubberized fabric bellows is used to clear the clogged riser pipes. Stamford uses two methods; the first method is back flushing with a fire hose; the second method is to radically increase the underflow rate from the clarifier's central return sludge well, thereby increasing the head of the siphon. Although the Stamford and Morganton methods are effective in cleaning the clogged riser pipes, they do constitute an additional operator task.

In Orange County's Sand Lake Road plant, Figures 131 and 135 clearly indicate an uneven sludge withdrawal by the traveling bridge airlift pumps. However, in this case, the "problem" may actually contribute to good clarifier performance. Perhaps the reader would like to speculate on the potential benefits of septic sludge near the center of large circular tanks.

Sludge header rotational speed is another design consideration. Sludge "freshness" is a factor. Peripheral or tip speed is a "design parameter" often quoted although the basis for limits of this parameter must be empirical. It is apparent from the comparative performance results at Morganton that lower rotational speeds may be beneficial in some cases. No deterioration in sludge quality was noted at Morganton despite a reduction in speed to 56% of design.

The position of the riser pipes at Stamford were such that they formed an effective, if intermittent reaction baffle or diffuser. The riser pipes tended to decrease the intensity of the inlet jets - the probable cause of the phenomenon which was illustrated in Figure 215. It is suggested that with a similar configuration elsewhere, a second set of dummy riser pipes at 90 degrees to the active set might be an effective and simple means of decreasing effluent suspended solids.

THE DENSITY CURRENT, SHORT CIRCUITS AND DEAD SPACES

From all the initial Flow Pattern/Solids Distribution Test results presented, it is difficult to differentiate between intentionally induced downflow and downflow which might have occurred without baffling. But Figure 65 suggests that downward flow developed quite near the central mixed liquor feed column at Morganton; all tracer emanated from the center near the tank's bottom. At Holly Hill, the investigator persisted in his attempt to minimize the density current effect, but the final hydraulic test series indicated near-failure.

In the spirit of "thinking like water", let us examine how the density current might develop despite very small specific gravity gradients:

In a typical mixed liquor settling test in the laboratory, very little settling occurs in the first few minutes. If the feedwell at Morganton could be thought of as a rather large settling test container, it would be difficult to predict the results of Figure 65. Influent rate to the feedwell was 3.044 mgd (11,522 m^3/d). With a 16 ft (4.9 m) diameter feedwell, downflow in the absence of a density current effect would be 1.41 ft/min (0.71 cm/s). Influent would just reach the bottom of the 10 ft (3.0 m) deep tank in 7 min. However, in 19 min, the tracer had actually traveled 10 ft (3.0 m) downward, 40 ft (12.2 m) outward, perhaps 3 ft (0.9 m) upward on the peripheral wall and 12 ft (3.7 m) back toward the center of the tank, a total of 65 ft (19.8 m). Clearly, a combination of throughflow and settling velocities has combined to produce the flow pattern. Velocities are certainly greater than can be accounted for by either influent rate alone or settling velocity alone.

This investigator perceives the developed density current effect seen in Figure 65 much like an established downdraft, formed as a result of the cumulative effect of the settling velocities of the many floc particles which have preceded the newly entering particles. Thus, if it were possible to start with a feedwell filled with mixed liquor, then introduce the influent mixed liquor, the inlet jets would initially impact the feedwell wall as jets, and, initially, flow downward at 1.41 ft/min (0.0071 m/s). However, a downdraft would gradually develop from the settling tendency (albeit small) of the particles. Eventually, the mixed liquor would appear to spill from the four inlet ports, closely resembling gentle waterfalls. This phenomenon, illustrated in Figure 216 , is believed to be the origin of the jets observed so clearly at Stamford. The Stamford jet may be best represented by Figure 216(B). The feedwells seem to be virtually ignored by the developed flow regime, at least at Morganton. (This hypothesis could be tested most easily by observing a typical tank's flow pattern after feedwell removal.)

Short circuits and dead spaces are departures from the theoretically ideal condition in settling tanks. They are not the causes of less-than-ideal settling behavior; they are merely two of the symptoms. Short circuits seem to result from the flow patterns established by the density currents. Dead spaces are those parts of a tank's volume which are not in the direct throughflow path. Usually, back eddies reside in the dead spaces. If the dead space is on the surface, it is usually warmed during the day, creating a stable condition because of the lower density of the warmer surface water. Temperature observations have suggested that this warmer water is gradually entrained in the throughflow. At night, when the surface is likely to cool, instability may result. The impact of these temperature phenomena on clarifier performance has not been assessed.

RETENTION TIME AND THE SMALL AMPLITUDE WAVE

Theoretical retention time, simply stated, is the time required to fill a tank of given volume at a given influent rate. In the ideal case, neglecting underflow, a mass of dye released instantaneously at a clarifier's inlet should travel as a plane surface to the discharge, exiting the tank instantaneously at $T = T_O$. This behavior has not been observed; the dye is always diffused and dispersed.

The dispersion test, which has been commonly used to meas-

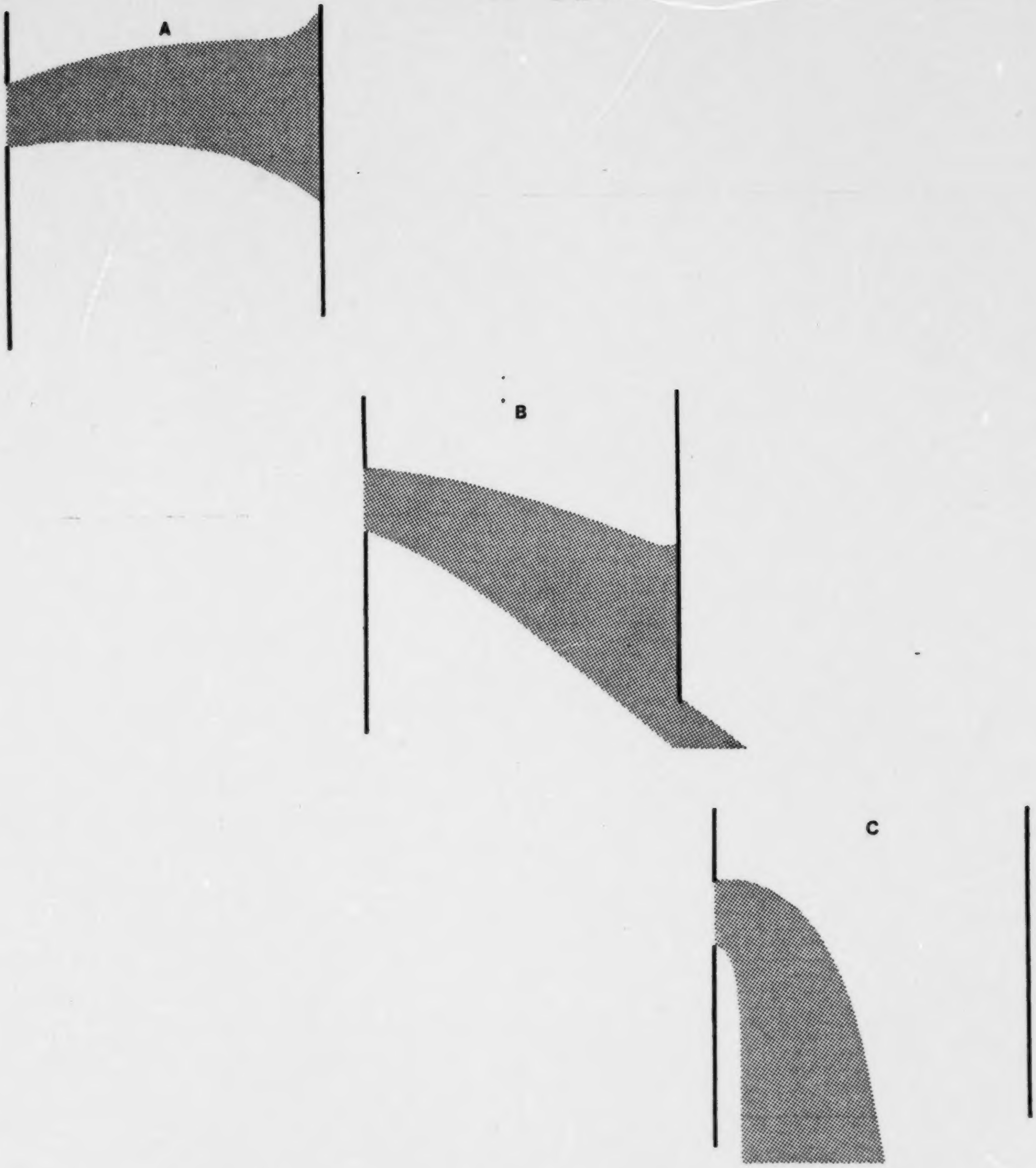


Figure 216. Simplified hypothetical development of a density current within the feedwell of a center feed, peripheral overflow clarifier. "A" is an initial condition; "B" shows the partially developed jet entering the tank proper; "C" represents the fully developed flow inferred from Morganton data.

ure the "hydraulic efficiency" of clarifiers, has many weaknesses, which were pointed out in Section 4. The single most widely used dispersion curve characteristic is T_{50}, the time required for 50% of dye passage. Within the limitations stated in Section 4 and the finite duration of the tests, the 7 dispersion-tested clarifiers in this study are compared in Table 31. Data presented are averages for all individual weir sampling points. No commentary is offerred; no significance is assigned to the results by the principal investigator.

TABLE 31. DISPERSION TEST COMPARISON OF SEVEN CLARIFIERS TESTED DURING THIS STUDY

Location	Test Date	Table Number	T_{50}(min)	T_o(min)	T_{50}/T_o
Albuquerque	20 Jun 79	2	91.2	143.2	0.637
Holly Hill	28 Feb 79	5	52.7	94.5	0.558
Morganton	29 Apr 79	9	97.4	129.8	0.750
Oakland(Main)	31 Jan 79	12	151.3	219.0	0.691
Oakland(P.W.)	6 Feb 79	14	124.1	297.4	0.417
Orange County	19 Sep 79	16	101.4	166.2	0.610
Stamford	6 Aug 79	20	113.1	167.5	0.675

The term retention time is widely misunderstood in a very significant sense. Retention time is in no way related to the time required for propagation of a flow rate change from the plant headworks to the final clarifiers unless flow equalizing storage volume intervenes. Since, in operation, all tanks are already full, the time required to overfill is infinitesimally small. Instead, the main factor controlling the speed with which flow rate changes propagate is the small amplitude wave speed[12,13]:

$$c = \sqrt{gh}$$

where c = speed of propagation of a small amplitude wave, in ft/sec
g = 32.2 ft/sec^2
h = water depth in ft

Neglecting relatively small boundary effects, a flow increase at the center of a tank of 65 ft (19.8 m) radius, with a 13 ft (4.0 m) depth will cause increased flow at the peripheral weirs in 3.2 sec. Thus, in a gravity flow plant, it can be expected that a flow change at the headworks will affect the secondary clarifiers within a minute or so. In Orange County's Sand Lake Road plant, where boundary effects in the long, narrow return sludge channel, Figure 217, are not negligible, the entire plant flow cycle was seen to require 4 min; Figure 137.

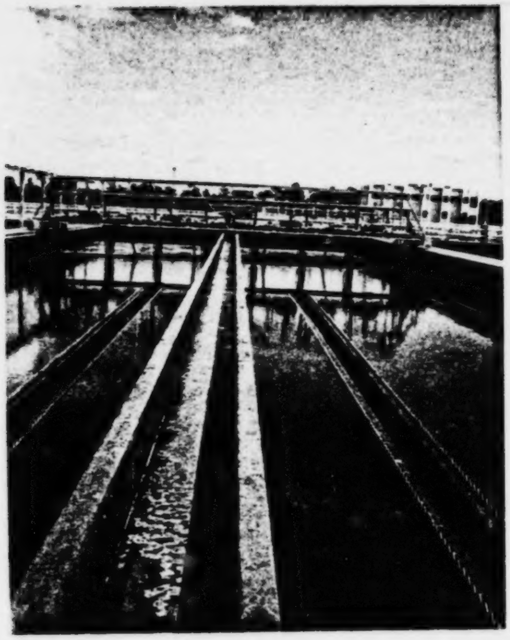


Figure 217. View from the weir end of Sand Lake Road secondary clarifier #1. The narrow return sludge channel starts in the lower left-hand corner of the photograph and flows toward the far end of the tank. In this view, the bridge is traveling away from the photographer.

FLOW MEASUREMENT AND CONTROL

Balance Between Clarifiers

Clarifier throughflow, sometimes called surface area overflow rate, is acknowledged as a used (if seldom useful) design parameter. If two or more identical clarifiers are operated in parallel, each should handle its share of the total hydraulic load. Yet hydraulic imbalances of the order of 20% were measured at Morganton and Stamford. Imbalances were suspected, but not measured, at Albuquerque and Orange County. Albuquerque, Holly Hill, Morganton, Orange County and Stamford, all plants with parallel secondary clarifiers, had no way for the operator to measure individual clarifier influent or effluent rate. The only available controls were gates. Gates, or gate valves are not satisfactory control devices because:

- They tend to catch rags and debris
- Their head loss characteristics vary with velocity, or flow rate.

For reasons which were not examined during this study, the splitter box and/or piping which fed mixed liquor to the Morganton secondaries resulted in imbalanced flow - sometimes to one unit, sometimes to the other. The unbalanced behavior of the Stamford splitter box could be understood. Figure 218 shows, schematically, the arrangement at Stamford. Mixed liquor flowing to the box at about 2 ft/s (61 cm/s) dissipates significant kinetic energy in colliding with the wall on which the gate valve to #2 secondary clarifier is located. Some of this loss is translated into additional static head on this wall. With the gate valves to #1 and #2 secondaries both fully open, #2 would receive a greater flow than #1. The flow difference measured at Stamford was about 20% during peak flow hours.

Imbalance is of little concern if hydraulic stress, causing poor effluent quality, is not a factor. However, hydraulic load distribution is worthwhile if the plant operator is to maximize performance under high flow conditions. The problem can be most effectively addressed during facility design by recognizing the effects of fluid momentum.

Balance Between Inlets

At Holly Hill, the poor flow distribution to four inlet ports on a common mixed liquor channel, Figure 42, was obvious although no absolute measurements were made. As with the splitter box distribution problem just described, the culprit seems to have been the physical conversion of kinetic energy into static head. The design procedure for inlet distribution at Holly Hill is unknown, but at least one widely used design reference[14] seems to neglect the effect.

The inlet distribution problem is not simple[15], but appears to involve a momentum loss and accompanying flow depth increase at each inlet port in addition to the end-of-channel kinetic-potential energy transformation resulting in another flow depth increase. If the common-channel flow distribution design scheme is to be continued, a more sophisticated design procedure needs to be developed in order to achieve good horizontal distribution of mixed liquor in individual clarifier inlet regions and clarifier-to-clarifier balance in cases of multiple clarifiers on a single mixed liquor channel.

Flow Measurement

Clarifier hydraulic loading can be completely defined by measurements of two flows:

1. Underflow rate.

2. Influent or effluent rate.

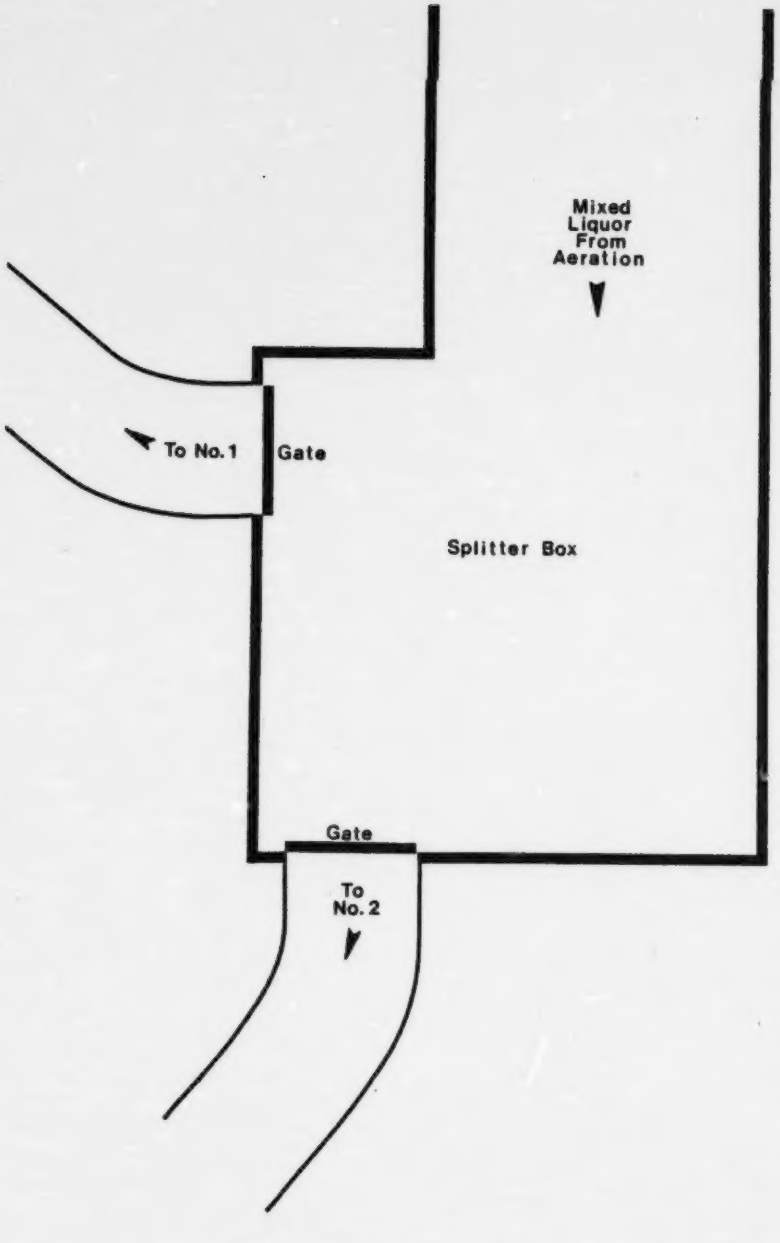

Mixed
Liquor
From
Aeration
To No. 1
Gate
Splitter Box
Gate
To
No. 2

Figure 218. Simplified plan view of the splitter box which feeds the secondary clarifiers at Stamford, CT.

Inexplicably, in cases of two or more parallel clarifiers, underflow is often metered individually, while neither mixed liquor feed nor overflow rate metering are often provided. Therefore, hydraulic balance can seldom be determined by the operator. The metering device need not be sophisticated. In the facility design stage, it is usually quite easy to provide for installation of measurement weirs and level guages. The level measuring device may be as simple as a meter-stick or point-guage. Availability of flow measurement devices will provide the operator with one more tool to assist him in optimizing plant effluent quality, especially when clarifiers reach flows which cause hydraulic stress.

Weir Leveling

The importance of weir leveling is not known. In the opinion of the writer, the throughflow route of a floc particle is largely determined by inlet-induced solids transporting effects. However, it is interesting to speculate about two special conditions:

1. A center feed, peripheral overflow circular clarifier is tilted so that all overflow is from one-half the weir circumference, Figure 219. The condition is not unrealistic; empty clarifiers have been known to float, and tilt, with high groundwater elevations. Since all overflow must exit the tank on the right-hand side, a confused flow pattern must result.

2. If, in a Stamford type clarifier, overflow weirs were blanked off in those sectors directly in line with the jet-producing inlet ports, the solids-laden jet flows would not have a direct path to the overflow weirs. A longer flow path would probably result in lower effluent suspended solids concentrations.

The uncertainty expressed in the two statements above points out the need for better understanding of the relative importance of weir location and active length. The answer might be contained in design standards[7], but the writer would like to see the evidence on which these standards are based.

WIND SHEAR, SEICHE AND SLOSH

In the last subsection, it was pointed out that the flow-distribution effects of differences in water surface elevation are not known. Thus, wind is discussed in concert with seiche and slosh, as factors which may influence the suspension of solids at the blanket. Seiche and slosh, which will be discussed subsequently, may be induced by wind gusts.

Although the effect on flow distribution is not known, it is instructive to examine wind set-up, the water surface slope

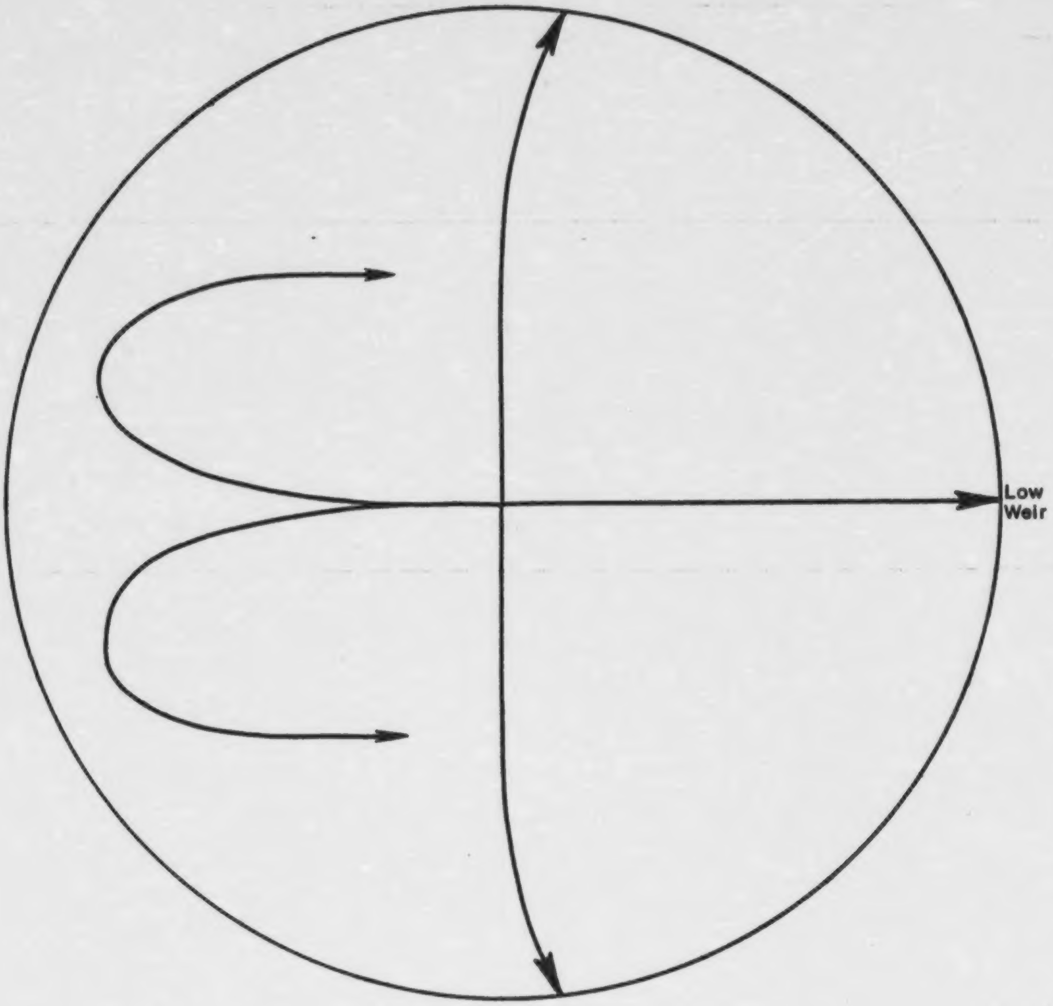


Figure 219. Hypothetical plan view of the flow pattern in a center feed, peripheral overflow clarifier with overflow weirs lower on the right-hand side.

which may be induced by steady winds. The effects of wind on the surface of a clarifier are often apparent only by the position or distribution of scum. Casual observation of subsurface particles leads to the conclusion that the fluid a few millimeters beneath the surface is not affected. Yet, it is well known from analysis of ocean currents and lake levels that wind effects are not negligible.

It is useful to examine a simplified analogy between lakes and clarifiers. By assuming a linear water surface slope, no water loss over the weirs, and a rectangular basin, it can be shown[16,17,18] that a 2.0 mm difference in end-to-end water elevation can result from commonly observed steady wind speeds. On typical clarifiers with V-notch weirs, a 3.0 mm difference in elevation is equivalent to a 20% difference in flow. The relationship between wind speed and set-up in rectangular basins of several dimensions is shown in Table 32.

TABLE 32. APPROXIMATE WIND SPEEDS CAPABLE OF CAUSING SURFACE ELEVATION DIFFERENCES OF 2mm IN A RECTANGULAR BASIN

Water Depth (m)	Basin Length (m)	Wind Speed (m/s)	Wind Speed (miles/hr)
2	10	15.4	34
2	30	5.1	11
2	50	3.1	7
4	10	30.8	69
4	30	10.2	23
4	50	6.2	14

In larger water bodies, on the scale of the Great Lakes, surface level oscillation due to wind or other atmospheric disturbances is well documented[17,19,20]. It is instructive to examine whether this type of oscillation (seiching) can occur in a basin the size of a clarifier. The period of the fundamental oscillation is related to the horizontal and vertical scale of a rectangular water body as follows:

$$T = \frac{2L}{\sqrt{gh}}$$

where T = period (seconds)
h = basin depth
L = basin length
g = acceleration of gravity.

In a clarifier, however, there are often two "free" surfaces: the visible water surface and the sludge blanket surface. An approximation of the period of the first harmonic of sludge blanket seiches can be made by the following related expression[17,21]:

$$T_i = \frac{2L}{\sqrt{\dfrac{g(S.G. - 1)h}{\left(\dfrac{h}{h_e} + \dfrac{h}{h_n}\right)}}}$$

where T_i = period of sludge blanket surface (seconds)
L = basin length
g = acceleration of gravity
S.G. = specific gravity of the sludge
h = overall basin depth
h_e = depth of clarified liquor above the blanket
h_n = thickness of the blanket.

Calculations for surface seiche periods of representative clarifier scales are presented in Table 33. Oscillation periods for the blanket may be double the time shown.

TABLE 33. PERIODS OF NATURAL (HARMONIC) SURFACE OSCILLATION FOR SEVERAL CLARIFIER SCALE RECTANGULAR BASINS

Water Depth (m)	Basin Length (m)	Time (sec)
2	10	4.5
2	50	25.0
4	10	3.2
4	50	16.0

For a circular basin, two types of seiching can occur. One type, which is symmetric about the vertical centerline of the tank, produces wave periods of approximately

$$T = 1.64 \frac{r}{\sqrt{gh}}$$

where r = the tank radius.

For a 3.0 m deep circular clarifier with a 20 m radius, a seiche period of about 6 seconds would be characteristic. A second type of seiche, called "sloshing", is symmetric about the centerline, extending across the diameter of the basin. This type of seiche has a characteristic period of

$$T = 3.41 \frac{r}{\sqrt{gh}}$$

For the same clarifier described above, the sloshing period would be about 12.6 seconds.

The major concern about seiche is the possibility that such disturbances may be caused by wind gusts or transient flow phenomena, such as those induced by lift stations or in-plant process pumps.

It seems particularly important to think of the possible cumulative effects of wind shear and the surface and internal (blanket) seiches which can occur simultaneously. If the wind induces a surface flow, it may either enhance or retard the usual backeddy flow, the lower part of which travels with the horizontal throughflow, atop the blanket. If surface seiche and slosh are occurring at the surface, the effect propagates downward to the blanket. But the blanket may be oscillating in yet another, unrelated mode. The effect of each phenomenon acts on the blanket as increased turbulence. Gentle turbulence may enhance flocculation. Intuition tells us that excessive turbulence is the antithesis of settling. The distinction between gentle and excessive turbulence has not been entirely defined.

As with several discussions which have preceded this one, we are left with a qualitative feel for the effects of physical phenomena on clarifier performances. A quantitative assessment of the importance of wind, seiche and slosh must be left to later research.

SOLIDS TRANSPORT, A PRELIMINARY MODEL

General

The treatment plant operator's concern is to produce the best possible effluent quality with the equipment which constitutes his plant. A major function of activated sludge secondary clarifiers is to intercept as much as possible of the suspended biological floc before the floc reaches the point of discharge. The floc accounts for most of the effluent's total suspended solids and some of the effluent's oxygen demand. The goal of this study has been to discover ways in which excessive floc particles reach the overflow weirs and to devise ways to keep at least some of that floc as far from the weirs as possible. The ease with which several clarifiers were improved is an indication of a need for revision of several common designs. Thus, at first glance, it seems futile to attempt to construct a mathematical model which is descriptive of treatment units which are less than ideal. However, the vast majority of clarifiers in the United States are probably represented by these imperfect units. They will not be replaced for many years. A model, of sorts, already exists[6] for ideal clarifiers, but ideal clarifiers probably do not exist.

The model proposed in this subsection differs from the ideal model in that it recognizes some real clarifier features not accounted for by Camp's derivation:

1. Horizontal throughflow is confined to a relatively narrow zone just above the blanket.

2. The narrow, horizontal throughflow zone is occupied by suspended solids which increase in concentration from the top to the bottom of the zone.

3. The flow rate may vary in amplitude and frequency.

As with most models, simplifications are necessary. In concept, the Solids Transport Model is only concerned with the region labeled Horizontal Flow in Figure 220. Figure 220 pictures a "representative" radial section of a center feed, peripheral overflow clarifier, similar to the units at Stamford. It is a simplified composite of all flow pattern test results presented in this report except those at Oakland, CA and Orange County, FL.

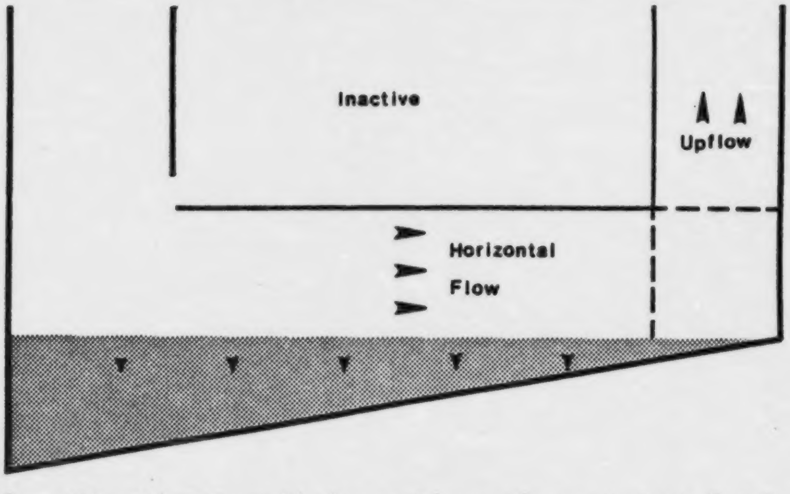


Figure 220. Idealized radial section of a center feed, peripheral overflow clarifier showing active and inactive flow zones. The shaded region at the bottom is the virtual blanket.

Those two examples are believed to be better represented by some variation of Camp's model, $v_o = Q/A$. Oakland's secondary #11 was potentially a steady flow case; automatic flow control was provided. Orange County's Sand Lake Road secondary #1 was far from a steady flow case, but the flow pattern and solids distribution was interpreted as nearly ideal despite unsteadiness.

The Solids Transport Model was derived by Collins[5] in order to attach a concise (if partial) physical explanation to the performance observations at Holly Hill, FL, where emplacement of a gate provided a storage effect which decreased the amplitude and frequency of flow variations and decreased effluent total suspended solids.

Several causes of flow disturbances have been discussed. Wind stress may cause an oscillation of calculable period, but as yet unknown amplitude. Normal diurnal flow variations and those from in-plant process pumps and upstream lift stations will propagate rapidly through a gravity plant with little smoothing. It has been reasonably well demonstrated that clarifier throughflows (in the units examined) occur just above the blanket, which has undergone minimal compaction at that depth. Intuition tells us that variation in throughflow rate will lead to a poorer environment for release of suspended solids to the underflow. The height of the active horizontal flow zone seems to be dictated by the settling character of the incoming mixed liquor.

Near the peripheral wall, clarified liquor moves upward toward the weirs, at least in the composite case, Figure 217. It is by no means certain that floc transported through the horizontal settling zone will reach the weirs. But it is reasonable to speculate that solids which reach the upflow zone will be roughly proportional to the fraction which is transported within the horizontal flow zone.

The Effects of Amplitude of Flow Variation

Collins' derivation of the Solids Transport Model was accomplished in two stages. The first stage considered only the amplitude of flow variations.

By any reasonable estimate, clarifier throughflows are turbulent, not laminar. Thus, eddies are present which can move particles upward within the horizontal bulk flow. If it is assumed that the thickness of the forward flow layer is constant, then at any radius, the horizontal flow, Q, will be directly proportional to velocity. Thus, in this discussion, flow and velocity may be used interchangeably. Turbulent diffusion due to flow induced velocity will result in upward movement of particles within the horizontal flow zone and cause a measurable gradient in solids concentration above the blanket, as shown conceptually in Figure 221. These suspended solids are, of course, moving radially. A general solution to the diffusion "model" results in a solids concentration gradient which is dependent on the particle settling velocity, the instantaneous mean fluid velocity and a friction factor. By further arithmetic manipulation, the model reduces to an equation which can be readily evaluated to estimate the relative increase in transport which can be expected from amplitude variations of flow alone:

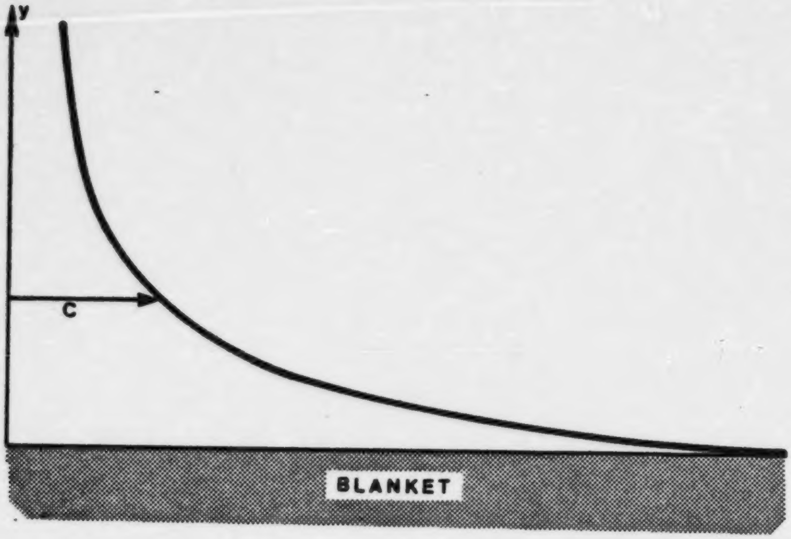


Figure 221. Hypothetical solids concentration gradient in the horizontal flow zone under low but steady through-flow conditions.

$$R = \frac{1}{T}\sum_{i=1}^{n} \left\{ \frac{Q}{\bar{Q}} \right\}^3 \Delta T \Bigg|_i$$

where R = relative solids transport due to amplitude variations in flow
T = period of time of the evaluation
n = number of equal time interval in the evaluation
Q = "instantaneous" flow rate during interval n
$\bar{Q}$ = average flow rate during T.

As an example of the potential impact of this development, an evaluation is shown for a normal diurnal flow curve measured in a small Texas City, Table 34 and Figure 222. The evaluation predicts that 60% more solids will be held in suspension and transported horizontally with the illustrated diurnal flow characteristic than would have been transported with the same average, but steady flow.

TABLE 34. CALCULATED RELATIVE INCREASE IN HORIZONTAL SOLIDS TRANSPORT DUE TO AMPLITUDE VARIATION IN FLOWS

Mean Flow = 1.533 mgd

Time (Hours)	Flow (MGD)	$(Q/\bar{Q})^3$
0000	2.000	2.220
0100	1.600	1.136
0200	0.900	0.202
0300	0.480	0.031
0400	0.300	0.007
0500	0.220	0.003
0600	0.220	0.003
0700	0.250	0.004
0800	0.490	0.033
0900	1.700	1.363
1000	1.870	1.814
1100	2.020	2.287
1200	1.980	2.154
1300	1.900	1.903
1400	1.960	2.089
1500	1.900	1.903
1600	1.750	1.487
1700	1.700	1.363
1800	1.920	1.964
1900	2.080	2.497
2000	2.100	2.570
2100	2.130	2.681
2200	2.360	3.647
2300	2.500	4.335
2400	2.000	2.220

Transport relative to steady flow = 1.597

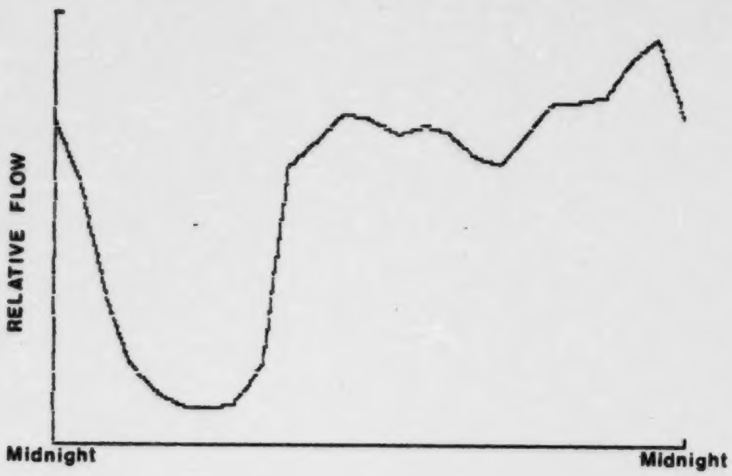


Figure 222. Normal dry weather diurnal flow curve for a small Texas City. Numerical data are shown in Table 34.

A similar evaluation was carried out on the one hour flow record from Holly Hill, Figure 30. The result was that only a 9.6% increase in transport could be predicted by the equation relative to steady flow conditions.

The comparative results at Holly Hill suggested that another phenomenon was operating.

The Frequency of Flow Variation Phenomenon

The second stage of development of the Solids Transport Model[5] includes a predicted effect from the frequency components of flow variability.

Within the confines of the forward flow layer, say at mid-radius, the turbulent environment produced by a steady flow rate of some magnitude will produce a measurable solids concentration gradient, somewhat like that which was shown in Figure 221. If a rapid flow rate increase occurs, the concentration gradient will be quickly changed to one which reflects the greater turbulent energy which has suddenly become available for moving the solids upward within the horizontal flow layer. This solids gradient will more nearly resemble that shown in Figure 223. However, reversion to the original, lower flow rate does not mean that the solids gradient quickly decreases to Figure 221 values. The turbulence resulting from higher velocities can be quickly established but will be very slow to die off. Thus, it would seem that the effects of a rapidly varying flow rate would be to establish a concentration gradient of unsettled solids in the horizontal flow layer which is more typical of

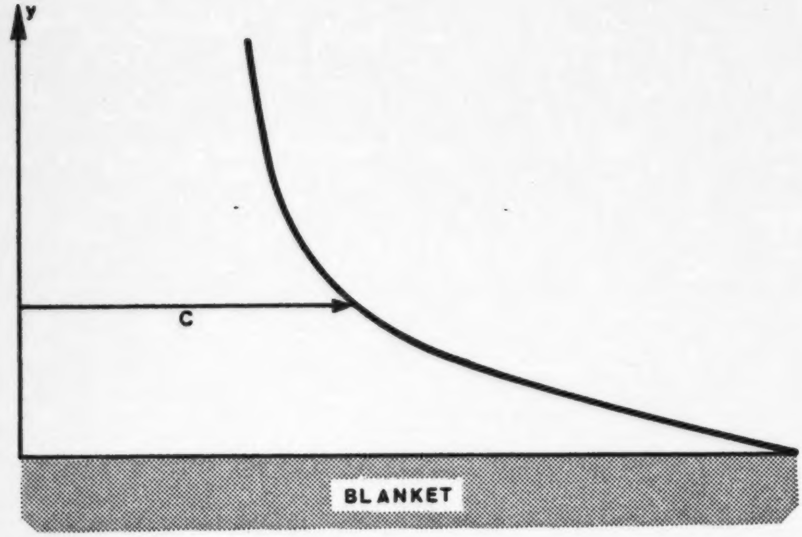


Figure 223. Hypothetical solids concentration gradient in the horizontal flow zone under high or unsteady throughflow conditions.

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higher flow rates than low or even average flow rates. The question is the definition of "rapid variation in flow rate". Does "rapid" imply frequencies of seconds, minutes or hours?

Collins' analytical treatment has made certain simplifying assumptions to describe the decay of turbulence and arrive at a basic time constant which estimates the rate of decay for the velocities such as those which are encountered. For example, if the depth of the flow layer is 1.5 m this basic time constant is 11 hours. This is, of course, considerably longer than a normal clarifier's "retention time". We will therefore assume that upstream flow events will have "flushed" the region within 2 hours, and adopt this as our basic time constant.

The model resorts to a simplified flow record such as that shown in Figure 224 and derives the relative transport function, R_{LF} for a low frequency case:

$$R_{LF} = (1+\alpha a)^2(1+\alpha a-a)\alpha\sigma(1-\exp(-2\beta T_c))+(\alpha-2\alpha\beta\sigma T_c)(1+\alpha a-a)^3+$$
$$(1-\alpha)(1+\alpha a)^3$$

where α = fractional time at low flow
$a = (Q_{(HIGH\ FLOW)}-Q_{(LOW\ FLOW)})/\overline{Q}$
$\sigma = 2\pi f/2\alpha\beta$
f = frequency of flow cycling in cycles/hour
$\beta = 1/C$
C = "Basic" time constant, in hours
$T_c = \beta^{-1} \ln ((1+\alpha a)/(1-(1-\alpha)a))$

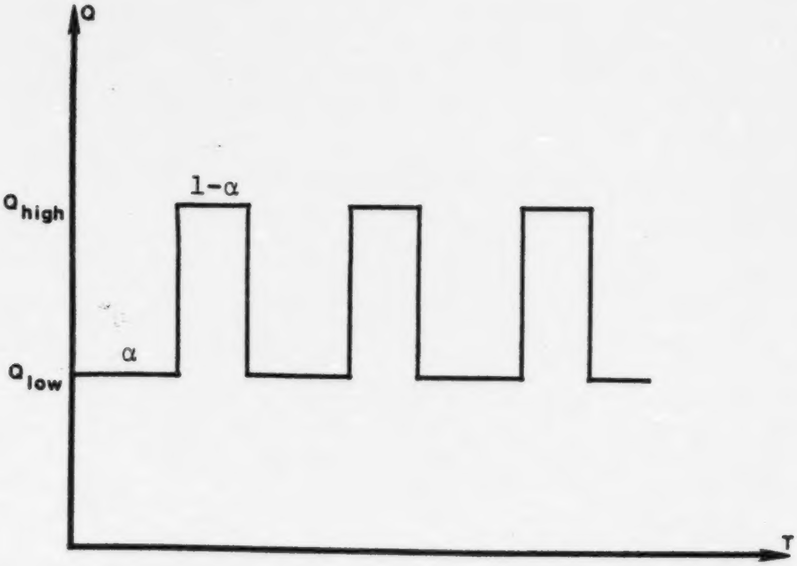

Figure 224. Transient Flow events such as might be experienced in a plant which is fed partially by gravity and partially by lift-station.

Although different in appearance, the results are roughly equivalent to the summation equation used to evaluate the flow record presented in Table 34. In other words, it is suitable for evaluation of diurnal effects. The analysis shows that the low frequency case only holds true if

$$2\pi f < \alpha\beta/\ln\{(1+\alpha a)/(1-(1-\alpha)a)\}$$

For $2\pi f \geq \alpha\beta/\ln\{(1+\alpha a)/(1-(1-\alpha)a)\}$, then the relative transport function is designated a high frequency case, R_{HF}:

$$R_{HF} = (1+\alpha a)^2(1+\alpha a-a)\alpha\sigma(1-\exp-(^1/\sigma))+(1-\alpha)(1+\alpha a)^3$$

The high frequency model may be more appropriate to flow events with periods of minutes to hours.

It should be stressed that there has been no verification of this model as yet. However, if it proves to be representative, it can be shown to be quite versatile in a practical, facility design sense. The following is an evaluation which approximates a "real world" flow condition in some treatment plants.

Example: Suppose that a waste treatment plant is subject to lift station operations at a frequency (f) of 4/hour. The basic time constant of the clarifier is taken to be 2 hours. We have the choice of operating the pumps continuously (α=o) or intermittently, such that they are running as little as 10% of the time (α=0.9). We evaluate this choice for on/off flow amplitude ratios of from 1:1 to 6:1 and for relative pump off times of 0.1, 0.3, 0.5, 0.7 and 0.9, with the result shown in Figure 225.

Figure 225 predicts that for a 10% duty cycle (α=0.9) with a 3:1 on/off flow ratio, solids transport will be more than 600% that of the smooth flow case. If, on the other hand, the pump remains on 90% of the time, the decrease in α and in Q_1/Q_2 ratio should result in much less transport. Thus, the use of smaller pumps with longer duty cycles could lead to a significant improvement in effluent quality.

Again, it will be emphasized that no mathematical model should be adopted, on faith, without verification. However, the Solids Transport Model presented is intuitively satisfying in that it addresses two of the flow related phenomena believed to affect secondary clarifier performance. The direction of the predicted results is correct. The absolute magnitudes of the predicted results are almost certainly in error.

FINAL CAUTIONARY NOTE

The writer wishes to stress one last time that the statements and opinions offered in this section should not be taken at face value, but appraised critically by the reader, in light of his own experiences. The writer's "philosophy" continues to evolve. Hopefully, he, his correspondents, and the readers of this report will all retain the ability to take advantage of new information as it becomes available. We are far from achieving a "cookbook" procedure for design and operation of settling tanks.

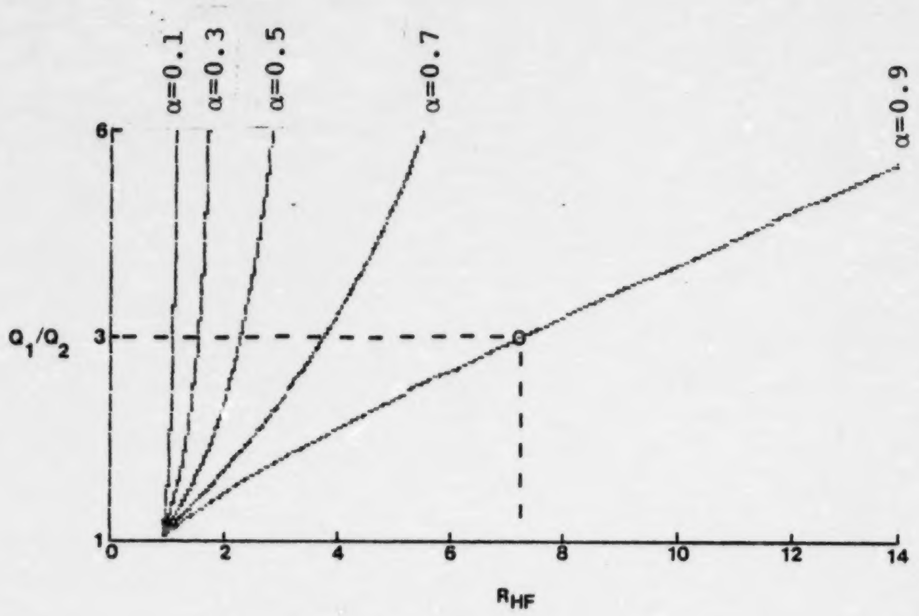

Figure 225. Predicted relative solids transport (R_{HF}) for flow amplitude ratios (Q_1/Q_2) of 1 to 6 and relative pump "off" times (α) of 0.1 to 0.9. Basic system time constant is 2 hours. Frequency of pump operation is 4/hour.

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APPENDIX A

LABORATORY DATA FOR THE HOLLY HILL WASTEWATER TREATMENT PLANT FOR DAYS OF INTENSIVE FIELD TESTING

Data sheets are as-supplied by the Holly Hill plant laboratory. Abbreviations in this appendix are, in order of presentation:

CFO - Clarifier overflow rate (mgd)
DOB - Depth of blanket (ft)
CSF - Clarifier underflow rate (mgd)
BLT - Blanket thickness (ft)
ATC - Aeration tank mixed liquor concentration, centrifuge (%)
MLSS - Mixed liquor suspended solids concentration (mg/l)
RSC - Return sludge concentration, centrifuge (%)
SVI - Thirty-minute sludge volume index
CSC - Clarifier sludge concentration (%)
BLV - Blanket volume (gal)
TSS_{60} - TSS of settleometer test supernatant in 60 min (mg/l)
CSU - Clarifier sludge units
IN - Inlet temperature (C)
CSFD - Clarifier sludge flow demand (mgd)
OUT - Outlet temperature (C)
ASU - Aeration sludge units
TSU - Total sludge units in the system
N,S - Under turbidity, North and South Clarifier effluent, units are Formalin Turbidity Units
CSUO - Clarifier sludge units overflow
CSPD - Clarifier sludge flow percentage demand (%)
CSDT - Clarifier sludge detention time (hours) (min)
XSC - Waste sludge concentration (%)
XSU - Waste sludge units
MCRT - Mean cell retention time (days)
FETSS - Final effluent TSS (mg/l)
WCR - Weight to concentration ratio
ESU - Effluent sludge units

Table A-1

Wednesday 28 Feb. 1979

Time: 0735			N	S	Time: 2000			N	S
CFO	1.18MGD	DOB	8.2'	8.1'	CFO	1.5MGD	DOB	8.2'	7.9'
CSF	.36MGD	BLT	1.0'	1.1'	CSF	.6MGD	BLT	1.0'	1.3'

ATC	3.0%	MLSS	1980	ATC	2.5%
RSC	5.5%	SVI	131	RSC	11.0%
CSC	4.25%	WCR	660	CSC	6.75%
BLV	16,336	TSS_{60}	17mg/l	BLV	17,892
CSU	694	IN	21°C	CSU	1207
CSFD	.099MGD	OUT	21°C	ASU	7750
ASU	9,300	Turbidity		TSU	8957
TSU	9,994	N	25 FTU	CSFD	.728
CSUO	825	S	25 FTU	CSPD	48%
CSDT	50 Min.				
CSPD	8.4%				
XSC	14%				
XSU	1,144				
MCRT	6.2				

0	1000	3.0	0	1000	2.5
5	500	6.0	5	500	5
10	375	8.0	10	400	6.25
15	310	9.7	15	350	7.1
20	290	10.3	20	310	8.0
25	275	10.9	25	300	8.3
30	260	11.5	30	275	9.0
40	250	12.0	40	255	9.8
50	240	12.5	50	250	10.0
60	240	12.5	60	250	
90	250		90	rising	
120	rising		120		

FETSS = 30

WCR = 747

ESU = 474

Table A-2

Thursday 1 Mar. 1979

Time: 0735

			N	S
CFO	1.13MGD	DOB	8.0'	7.9'
CSF	.46MGD	BLT	1.2'	1.3'

ATC	3%	MLSS	2148
RSC	7%	SVI	135
CSC	5%	WCR	716
BLV	19448	TSS_{60}	13mg/l
CSU	972	IN	20°C
CSFD	.46MGD	OUT	20°C
ASU	9300	Turbidity	
TSU	10272	N	28 FTU
CSUO	1344	S	26 FTU
CSDT	43min.		
CSPD	41%		
XSC	14.5%		
XSU	1185		
MCRT	6.0		

0	1000	3.0
5	540	5.6
10	400	7.5
15	350	8.6
20	310	9.7
25	300	10.0
30	290	10.3
40	290	10.3
50	rising	
60		
90		
120		

Time: 2000

			N	S
CFO	1.35	DOB		
CSF	.55	BLT	1.1'	1.4'

ATC	2.7%
RSC	11%
CSC	6.85%
BLV	20225
CSU	1385
ASU	8370
TSU	9755
CSFD	.702
CSPD	52.0%
TSS_{60}	8mg/l
TEMP.	
IN	23°C
OUT	23°C

0	1000	2.7
5	500	5.4
10	390	6.9
15	330	8.2
20	300	9.0
25	300	9.0
30	295	9.2
40	290	9.3
50	290	
60	290	
90	rising	
120		

FETSS = 30

WCR = 660

ESU = 513

Table A-3

Monday 26 Mar. 1979

Time: 0715			N	S	Time: 2000 Wall			N	S
CFO	1.0MGD	DOB	8.2'	5.6'	CFO	1.45MGD	DOB		
CSF	.35MGD	BLT	1.0'	3.6'	CSF	.60MGD	BLT	1.5	1.5
ATC	2.%	MLSS	1604		ATC	3.0%			
RSC	9.5%	SVI	109		RSL	10.0%			
CSC	5.75%	WCR	802		CSC	6.5%			
BLV	35,783	TSS_{60}	-32		BLV	23,337			
CSU	2,057	IN	19°C		CSU	1,517			
CSFD	.240	OUT	19°C		ASU	9,300			
ASU	6,200	Turbidity			TSU	10,817			
TSU	8,257	N	9 FTU		CSFD	.356			
CSUO	1,385	S	22 FTU		CSPD	24.5%			
CSDT	89 min.				TSS_{60}	8mg/l			
CSPD	24%				IN	21°C			
XSC	10%				OUT	21°C			
XSU	149.1								
MCRT	4.9								

0	1000	2		0	1000	3.0	
5	340	5.8		5	500	6.0	
10	250	8.		10	375	8.0	
15	220	9.		15	325	9.2	
20	200	10.		20	300	10.0	
25	190	10.5		25	280	10.7	
30	175	11.4		30	255	11.8	
40	155	12.9	◄ TARGET	40	250	12.0	
50	150	13.3		50	240	12.5	
60	150			60	220	13.6	14.8 ◄ TARGET
90	--			90	200	15.0	
120	--			120	200	----	

FETSS = 15

WCR = 780

ESU = 192

Table A-4

Tuesday 27 Mar. 1979

Time: 0735			N	S	Time: 2000 Bromberg			N	S
CFO	1.1MGD	DOB	7.8'	7.8'	CFO	1.5	DOB	4.0'	5.0'
CSF	.46MGD	BLT	1.4'	1.4'	CSF	.6	BLT	5.2'	4.2'

ATC	3.5%	MLSS	2,932	ATC	2.5%
RSC	11.%	SVI	110	RSL	9.%
CSC	7.25%	WCR	837	CSC	5.75%
BLV	21,781	TSS_{60}	27	BLV	73,122
CSU	1,579	IN	20.5°C	CSU	4204
CSFD	.348	OUT	20°C	ASU	7,750
ASU	10,850	Turbidity		TSU	11,954
TSU	12,429	N	6.4 FTU	CSFD	.414
CSUO	2,108	S	7.2 FTU	CSPD	27%
CSDT	45 min.			TSS_{60}	-32
CSPD	32%			IN	20°C
XSC	11			OUT	20°C
XSU	1693				
MCRT	5.9				

0	1000	3.5	0	1000	2.5
5	660	5.3	5	500	5.
10	500	7.	10	400	6.25
15	440	7.9	15	350	7.1
20	390	8.9	20	300	8.3
25	350	10.	25	290	8.6
30	325	10.7	30	260	9.6
40	300	11.6	40	250	10.
50	275	12.7	50	225	11.1
60	260	13.4 ◄ TARGET	60	210	11.9 ◄ TARGET
90	225	15.5	90	205	12.1
120	210	16.6	120	---	

FETSS = 30　　WCR = 802　　ESU = 411

Table A-5

Wednesday 28 Mar. 1979

Time: 0745					Time: 2000 Bromberg				
			N	S				N	S
CFO	1.1MGD	DOB	8'	6'	CFO		DOB	6.6'	7.4'
CSF	.39MGD	BLT	1.2'	3.2'	CSF		BLT	2.6'	1.8'

ATC	2.4%	MLSS	2024	ATC	3.%
RSC	16%	SVI	98.8	RSL	11.%
CSC	9.2%	WCR	843	CSC	7.%
BLV	34,228	TSS_{60}	28	BLV	34,228
CSU	3,149	IN	20°C	CSU	2396
CSFD	.469MGD	OUT	20°C	ASU	9300
ASU	7,440	Turbidity		TSU	11,696
TSU	10,589	N	39 FTU	CSFD	.466
CSUO	2,600	S	20 FTU	CSPD	31%
CSDT	1.2 hr.			TSS_{60}	
CSPD	43%			IN	20°C
XSC	12.5			OUT	20°C
XSU	1503				
MCRT	6.0				

0	1000	2.4		0	1000	3.%	
5	410	5.8		5	600	5.	
10	300	8.0		10	450	6.6	
15	250	9.6		15	375	8.	
20	240	10.0		20	340	8.8	
25	210	11.4		25	310	9.6	
30	200	12.0		30	300	10.	
40	190	12.6		40	250	12.	
50	175	13.7		50	250	12.	
60	175	13.7	◄ TARGET	60	225	13.3	◄ TARGET
90	160	15.0		90	210	14.2	
120	160	15.0		120	---		

FETSS = 20 WCR = 837 ESU = 263

Table A-6

Thursday 29 Mar. 1979

Time:	0740				Time:	2000 Wall			
			N	S				N	S
CFO	1.1MGD	DOB	6.8'	7'	CFO	1.45MGD	DOB	7.8'	6.8'
CSF	.585MGD	BLT	2.4'	2.2'	CSF	.60MGD	BLT	1.4'	2.4'

ATC	3.9%	MLSS	2,992	ATC	3.0%
RSC	9%	SVI	147	RSL	9.5%
CSC	6.45%	WCR	767	CSC	6.25%
BLV	35,783	TSS_{60}	5	BLV	29,560
CSU	2,308	IN	20°C	CSU	1,848
CSFD	.368MGD	OUT	20°C	ASU	9,300
ASU	12,090	Turbidity		TSU	11,148
TSU	14,398	N	5.4 FTU	CSFD	.325
CSUO	2,194	S	4.6 FTU	CSPD	22.4%
CSDT	1 hr.			TSS_{60}	**
CSPD	33%			IN	21°C
XSC	13%			OUT	21°C
XSU	2,314				
MCRT	5.1			** TESTING	

0	1000	3.9	0	1000	3.0
5	900	4.3	5	545	5.5
10	740	5.3	10	400	7.5
15	610	6.4	15	350	8.6
20	540	7.2	20	310	9.7
25	475	8.2	25	300	10.0
30	440	8.9	30	280	10.7
40	390	10.0	40	250	12.0
50	350	11.1	50	245	12.2
60	325	12.0 ◄ TARGET	60	225	13.3
90	275	14.1	90	200	15.0 ◄ TARGET
120	260	15.0	120	195	15.4

FETSS = 40 WCR = 843 ESU = 522

Table A-7

Tuesday 28 Aug. 1979

Time: 0730

			N	S
CFO	1.2MGD	DOB	-	
CSF	.35MGD	BLT	1.2'	
ATC	4.0%	MLSS	2714	
RSC	12.0%	SVI	128	
CSC	8.0%	WCR	679	
BLV	18,669	TSS_{60}	4	
CSU	1493	IN	27°C	
CSFD	200	OUT	27°C	
ASU	12,400	Turbidity		
TSU	13,893	N		
CSUO	1750	S		
CSDT	51 min.			
CSPD	16%			
XSC	19%			
XSU	2924			
MCRT	4.6			

Time: 2000 Wall

			N	S
CFO	1.60MGD	DOB	8.0'	avg.
CSF	.62MGD	BLT	1.2'	avg.
ATC	3.5%			
RSC	11.0%			
CSC	7.25%			
BLV	18,670			
CSU	1354			
ASU	10,850			
TSU	12,204			
CSFD	.489			
CSPD	31%			
TSS_{60}	5mg/l			
IN	28°C			
OUT	28°C			

0	1000	4.0	
5	550	7.3	
10	550	7.3	
15	500	8.0	
20	400	10.0	
25	350	11.4	
30	350	11.4	
40	300	13.3	
50	250	16.0	
60	250	16.0	18.0 ◄ TARGET
90	200	20.0	
120	200	20.0	

0	1000	3.5	
5	580	6.0	
10	450	7.7	
15	400	8.7	
20	360	9.7	
25	350	10.0	
30	325	10.8	
40	305	11.5	
50	300	11.7	
60	280	12.5	
90	275	12.7	13.0 ◄ TARGET
120	260	13.5	

FETSS = 7

WCR = 783

ESU = 107

APPENDIX B

HOLLY HILL, FLORIDA OPERATING AND PERFORMANCE DATA FOR THE PERIOD 12 MARCH TO 3 DECEMBER 1979

The following three criteria were used for selection of data (marked*) for comparative averages:

1. Total suspended solids composites for both the south, or test clarifier (STSS) and the north, or control clarifier (NTSS) were available.

2. The position of the channel storage gate was known. (1) means that storage was being used; the gate was in place. (2) means that storage was not being used; the gate was removed. (3) means that it was impossible to determine whether the gate was in place or not.

3. The thickness of the sludge blanket, at mid-tank, was measured by optical sensor as less than 2 ft.

Units of the columns are:

Flow - total (mgd) 24 hr plant flow
MCRT - mean all retention time (days)
NTSS - composite effluent TSS, north (control) clarifier (mg/l)
STSS - composite effluent TSS, south (test) clarifier (mg/l)
MLSS - mixed liquor suspended solids concentration (mg/l)
Blanket - thickness at mid-tank (ft)

	DAY	FLOW	UNDER FLOW(%)	MCRT	NTSS	STSS	MLSS	SVI	GATE	N BLANKET	S BLANKET
12 March 79	1	1.435	40	6	44	21	2895	152	2	1.6	2.1
	2	1.318	51	5.8	28	44	2840	155	2	2	3.1
	3	1.288	38	5.7	62	10	2948	178	2	1.7	2.1
	4	1.257	40	5.4	30	41	2868	153	2	1.6	2.1

	DAY	FLOW	UNDER FLOW(%)	MCRT	NTSS	STSS	MLSS	SVI	GATE	N BLANKET	S BLANKET
	5	1.207	57	5.5	69	53	2568	136	2	1.3	2.1
	*6	1.187	47		77	73	2952	162	2	1.3	1.9
	7	1.134	55	6	32	94	3522	124	2	1.3	2.3
	8	1.212	42	6	23	28	3209	123	2	1.3	2.4
	9	1.18	51	4.9	37	35	3056	111	2	1.4	2.1
	10	1.143	50	5.3	22	16	2912	106	2	1.6	2.1
	*11	1.158	42	4.7	30	23	2896	121	2	1.4	1.4
	*12	1.092	39	4.8	50	29	2832	106	2	1	1.2
	*13	1.079	48	6	35	14	2897	107	2	1.1	1.1
	14	1.01	36	6	17	9	2732	109	3	.9	1.1
	15	1.089	42	4.9	25	42	1604	109	1	1.3	2.6
	16	1.105	36	5.9	30	10	2932	110	1	3.3	2.8
	17	1.108	53	6	50	44	2024	99	1	1.9	2.5
	18	1.064	33	5.1	13	23	2992	147	1	1.7	2.3
	19	1.064	47	5.5	18	8	1192	105	1	2.1	2.6
	20	1.031	32	6.2	14	15	2706	203	1	1.8	2.6
1 April 79	21	.948	39	6	10	4	2395	150	1	1.1	2.2
	*22	1.088	37	5.9	16	10	2717	128	2	1.6	1.9
	23	1.017	43	5.7	8	4	2884	104	2	2.3	2.5
	*24	1.023	45	4.5	14	10	3296	114	2	1.5	1.7
	*25	1.039	63	4.8	23	25	3012	103	2	1.2	1.2
	*26	.994	58	4.1	15	4	3092	94	2	1.2	1.3
	*27	1.021	45	6	25	49	2001	95	2	.9	1.4
	*28	.944	43	6.1	23	22	2748	91	2	.9	1
	*29	1.049	53	5.1	13	31	2572	93	2	1.2	1.2
	*30	1.069	45	5.7	8	32	2628	95	1	.9	1.2
	*31	1.056	39	5.1	10	14	2864	96	1	1.2	1.3
	*32	1.037	34	3.8	30	40	2868	84	1	.9	1
	*33	1.039	48	4.8	21	24	2604	81	1	.7	1
	*34	1.041	39	6	41	22	2516	99	1	.9	.8
15 April 79	*35	.918	44	5.8	18	32	2492	100	1	.8	.7
	*36	1.019	40	6.3	17	10	2412	101	1	1.1	1.1
	*37	.999	39	6.1	40	12	2620	95	1	.8	.8
	38	1.009	34	5.6	18		2528	103	1	1.2	1.2
	*39	1.009	36	5.9	26	19	2392	104	1	1.1	1.1
	*40	1.093	43	6	17	6	2924	103	1	1	1
	*41	.959	35	6	45	15	2532	118	1	1	1.3
	*42	.876	38	7	6	10	2382	109	1	1	.7
	*43	.958	34	9.7	24	9	2776	94	1	1.1	1.1
	*44	1.027	31	6.8	10	6	2264	115	1	.5	.9
	*45	1.187	32	6.1	12	14	2508	116	2	1.2	1.3
	*46	1.211	33	5.9	43	26	2436	119	2	1	1.7
	*47	1.084	35	5.3	26	24	2852	109	2	1.1	1.5
	*48	1.022	33	6.6	45	50	2832	105	2	.6	1.2
	*49	.947	41	6.5	18	31	2308	140	2	.9	1.8
	50	1.291	49	5.8	18	46	2164	97	2	.8	2.2
1 May 79	51	1.45	43	6.6	22	20	2248	89	2	1	2.2
	52	1.479	34	5.5	24	32	3244	85	2	1.6	2.1
	*53	1.265	33	5.1	43	43	3148	82	2	1.2	1.2

	DAY	FLOW	UNDER FLOW(%)	MCRT	NTSS	STSS	MLSS	SVI	GATE	N BLANKET	S BLANKET
	*54	1.163	33	5.7	41	35	3120	83	2	.9	1.2
	*55	1.131	34	6	35	30	3056	82	2	1.1	1.1
	*56	.956	42	5.8	35	33	2976	84	2	.7	.7
	*57	1.349	39	6.2	37	38	2840	70	2	1	1
	*58	2.204	25	5.2	29	19	2688	74	2	1.3	1.3
	59	2.2	20	5.8	29	19	868	230	2	1.6	2.1
	*60	1.868	29	7.7	25	26	2780	72	2	1	1.5
	61	1.65	28	7.6			3068	73	2	1.2	1.2
	*62	1.535	24	5.3	26	24	3064	73	2	1.3	1.3
	*63	1.375	38	5	39	22	2260	49	2	1.3	1.3
	64	1.533	36	3.8			2791	81	2	1.2	1.3
15 May 79	*65	1.434	35	7.9	21	21	3124	72	2	1.2	1.4
	*66	1.402	31	7.2	32	14	3212	75	2	1.3	1.3
	*67	1.326	35	5.9	29	21	3444	73	2	1.3	1.3
	*68	1.229	41	6.7	38	15	3564	70	2	1.9	1.5
	*69	1.2	43	6.5	38	15	3760	73	2	1.2	1.2
	*70	1.15	46	6.7	40	19	3484	72	2	1.1	1.1
	71	1.243	46	5.3			2940	68	2	1.1	1.1
	*72	1.201	46	5.6	25	24	3584	67	2	1.5	1.3
	*73	1.117	35	5.3	18	26	3516	71	2	1.4	1.2
	*74	1.119	37	4.6	9	19	3224	78	2	.7	1.1
	75	1.119	37	4.5			2968	71	2	.6	.7
	*76	1.056	45	5.6	6	17	2352	85	2	.5	.6
	77	.968	47	3.5			2356	85	2	.7	.7
	78	1.079	53	5.5	11	7	2160	93	3	.6	.7
	*79	1.089	34	5.4	12	13	1964	107	1	.7	.7
	*80	1.056	41	5.5	11	9	2560	94	1	.6	.7
	*81	1.07	42	5.5	11	13	2364	102	1	.6	1
1 June 79	82	1.092	28	5.5			2248	113	1	.9	1
	*83	1.03	31	5.5	15	9	2228	112	1	.8	1
	*84	1.009	33	5.6	15	20	2236	134	1	.8	1
	*85	1.116	31	6	1	3	2171	138	1	1.1	1.1
	*86	1.189	31	5.5	18	15	2363	127	1	1.2	1.2
	*87	1.195	25	5.5	17	11	2229	112	1	1.2	1.2
	*88	1.285	26	5.2	24	17	2480	137	1	1	1
	*89	1.178	27	4.3	16	8	2436	133	1	1.1	1.3
	*90	1.076	26	4.5	15	9	2442	102	1	1.1	1.1
	*91	1.064	39	5.1	11	12	2560	117	2	1.4	1.4
	*92	1.138	27	3.7	12	15	2664	128	2	1.1	1.1
	*93	1.064	21	5.5	11	14	2144	140	2	1.2	1.2
	*94	1.099	39	4.8	33	28	2008	125	2	.9	.9
	*95	1.083	34	4.7	12	11	2000	130	2	.9	1
15 June 79	*96	1.151	30	4.8	15	9	2024	124	2	.9	.9
	*97	1.084	37	5.4	24	14	2427	124	2	1	1.2
	*98	1.032	29	5.1	12	9	2261	132	2	1	.8
	*99	1.174	27	4.2	17	13	1692	118	1	.5	.6
	*100	1.274	30	5	12	13	1760	114	1	.7	.7
	*101	1.214	38	5	17	15	2500	120	1	.7	.7
	*102	1.113	36	4.1	18	9	2472	111	1	.8	.7

	DAY	FLOW	UNDER FLOW(%)	MCRT	NTSS	STSS	MLSS	SVI	GATE	N BLANKET	S BLANKET
	103	1.08	42	5			2572	113	1	1.1	.9
	104	1.048	36	5.4			2624	114	1	1	1
	*105	1.038	39	5	14	10	2160	138	1	1.1	1
	106	1.189	23	5	12	11	2384	115	3	1.1	.9
	107	1.121	31	5			2488	117	3	1	1.1
	108	1.229	33	5	13	15	2261	133	3	1.1	1
	*109	1.127	28	5	14	12	2548	118	2	1.1	.8
	*110	1.13	33	4.6	14	13	2300	113	2	1	.8
	*111	1.095	28	5.1	13	12	2472	81	2	1	.9
1 July 79	112	1.056	30	5.1			2427	124	2	1.1	1.1
	*113	1.127	32	5.1	8	6	2548	98	2	1.2	1.2
	*114	1.12	31	4.6	14	10	2788	108	1	.9	.9
	*115	.996	36	5	16	9	2868	105	1	1.2	1.2
	116	1.132	31	5			2620	115	1	1.1	1.1
	*117	1.12	34	4.3	17	11	2564	113	2	1	1
	*118	1.061	40	4.9	18	15	2671	109	2	1	.9
	*119	1.255	24	5	19	19	2722	73	2	1	.9
	120	1.41	24	5.2	43	31	2732	110	3	1	1.2
	*121	1.365	34	5.1	36	24	2353	127	2	1	1
	*122	1.448	24	5	39	27	3428	102	2	1.8	1.6
	123	3.24	9	3.4	59	24	2856	108	2	2.3	2.3
	124	2.032	16	3.2			2912	98	2	1.4	1.2
	125	1.692	21	5			2857	96	2	1.2	1.2
15 July 79	*126	1.441	20	5	22	27	2794	107	2	1.2	1.1
	*127	1.473	32	5	30	30	2817	89	2	1.2	1.2
	*128	1.565	28	4.9	24	34	2914	86	2	1.3	1.3
	129	1.6	28	4.4			2564	97	2	1.2	1.3
	*130	1.486	34	5	46	38	2828	88	2	1.3	1.4
	*131	1.407	27	5	30	23	2568	97	2	1.2	1.2
	*132	1.314	32	5.1	20	21	2611	144	2	1.2	1
	*133	1.206	33	5	26	17	2721	74	2	1.3	1.2
	*134	1.289	25	4.9	37	26	2714	110	2	1.2	1.2
	*135	1.275	24	4.5	41	19	2980	109	2	1.3	1.3
	*136	1.253	35	4.9	43	31	2976	101	2	1	1
	*137	1.221	37	5	24	31	3300	97	2	.8	1
	*138	1.199	34	5	31	17	3000	108	2	1.2	1.1
	*139	1.183	35	5	27	23	2873	87	2	1.3	1.1
	*140	1.131	26	5	33	34	2777	135	2	1.4	1.3
	*141	1.195	25	5	53	31	2832	141	2	1.5	1.5
	*142	1.185	31	5	48	23	2901	120	1	1.6	1.4
1 August 79	*143	1.201	29	4.6	29	23	3244	129	1	1.6	1.6
	*144	1.227	28	4.5	21	18	3012	121	1	1.5	1.6
	145	1.221	31	4.5			2920	140	1	1.8	1.4
	146	1.147	39	4.5			2851	105	1	1.3	1.2
	147	1.114	33	4.5			2814	124	1	1.1	1
	*148	1.183	30	4.6	15	17	2798	178	2	1.1	1.2
	*149	1.137	32	4.6	19	17	2652	132	2	1.2	1.2
	150	1.228	28	4.5	18	18	2708	148	2	2.4	2.5
	*151	1.221	29	3.8	8	7	2744	146	2	1	1.1

	DAY	FLOW	UNDER FLOW(%)	MCRT	NTSS	STSS	MLSS	SVI	GATE	N BLANKET	S BLANKET
	*152	1.353	30	4.5	12	12	2432	154	2	.9	1.2
	*153	1.424	26	4.5	13	13	2794	214	2	1.2	1.2
	*154	1.332	27	4.6	18	21	2727	110	2	.9	1
	*155	2.189	12	4.5	24	17	2751	181	2	1.3	1.2
	156	1.889	24	4.6			2814	106	2	1.3	1.2
15 August 79	157	1.894	24	4.1	22	18	2200	136	2		
	158	1.888	24	4.5	23	22	2300	130	2		
	159	1.68	33	4.5	17	16	2240	145	2		
	160	1.55	30				2364	148	2		
	161	1.432	31	4.6			2652	141	2		
	162	1.466	28	4.5	10	9	3460	86	2		
	163	1.443	34	4.6			2948	169	2		
	164	1.381	42	4.6	11	10	2948	169	2		
	165	1.318	38	4.5	9	12	2784	180	2		
	166	1.376	31	4.5	10	8	2696	182	2		
	167	1.252	32	4.6	13	22	2684	242	2		
	168	1.221	36	4.5	10	7	2714	193	2		
	169	1.259	28	4.6	7	7	2742	127	1		
	170	1.276	30	4.6	11	9	2714	128	1		
	171	1.272	33	4.5	65	6	2792	143	1		
	172	1.27	41	4.5	13	15	3640	179	1		
	173	1.199	36	4.5	15	14	3780	159	1		
1 Sept 79	174	1.298	34	4.5			3215	202	2		
	175	1.306	50	4.4	20	23	3182	157	2		
	176	2.011	21	5.2			2524	188	2		
	177	2.483	27	4.5			2717	92	2		
	178	2.547	26	4.6			2984	84	2		
	179	2.511	24	5.8	22	24	3416	102	2		
	180	2.146	27	4.5	26	22	2804	98	2		
	181	1.698	31	4.4			2945	136	2		
	182	2.152	31	4.5			2894	155	2		
	183	2.093	23	4.6	40	33	2636	114	2		
	*184	1.755	23	3.5	30	25	972	102	2	1.2	1.2
	*185	1.667	38	4.5	30	30	3220	116	2	1.4	1.3
	186	2.654	14	4.6			2908	120	2	.6	.3
	*187	3.424	13	4.5	30	63	1880	93	2	1.5	1.2
15 Sept 79	188	3.075	17	4.4			2047	147	2	.7	.7
	*189	2.023	31	3.7	34	51	2142	140	1	.5	.4
	*190	1.941	30	4.3	32	43	2647	76	1	.8	.8
	*191	1.793	40	4.4	27	21	2714	74	1	1.2	1.2
	*192	1.599	25	4.1	18	20	2728	92	1	1.2	1.2
	*193	1.646	28	4.6	13	12	2392	100	1	.6	.6
	*194	1.617	22	4.4	18	20	2080	108	1	.8	.8
	195	3.403	13	4.4			2194	114	2	.7	.6
	196	2.986	15	4.6			2204	113	2	.7	.6
	*197	3.542	11	4.6	50	49	2460	98	2	1	1
	*198	2.576	17	4.2	48	41	1472	109	2	1.3	1.1
	*199	2.495	18	4.4	21	63	1772	113	2	.9	1.2
	*200	2.052	23	4.5	14	53	2116	118	2	1.4	1.1

	DAY	FLOW	UNDER FLOW(%)	MCRT	NTSS	STSS	MLSS	SVI	GATE	N BLANKET	S BLANKET
	*201	1.833	17	4.5	16	34	2628	114	2	.8	1
	202	2.507	13	4.5			2714	157	2	.8	.6
	203	2.101	18	4.6			2872	104	2	.8	.8
1 October 79	*204	1.978	20	4.6	23	30	2848	123	2	1	1.5
	*205	1.811	19	4.5	23	30	2794	125	2	1.8	1.6
	*206	1.701	25	4.5	12	13	2604	144	1	1.2	1.6
	*207	1.661	19	4.5	33	10	2720	137	1	1	1.7
	208	1.558	23	4.5			2412	161	1	1	1.3
	209	1.425	20	4.5			2561	176	1	.9	.7
	210	1.393	29	4.6			2514	189	1	.7	.8
	211	1.477	33	4.5			2923	171	1	1	.7
	*212	1.411	28	4.5	96	29	2884	173	2	1.8	1.1
	*213	1.393	30	4.6	54	12	2472	202	2	.7	.3
	214	1.376	22	4.5			2720	220	2	.7	.8
	215	1.265	24	4.5			2608	210	2	.6	.7
	*216	1.262	27	4.5	48	14	2673	243	2	.6	.7
	*217	1.216	30	4.6	58	13	2621	229	2	.6	.8
15 October 79	218	1.282	35	5.7	274	11	2676	224	3	1.2	1.4
	219	1.316	34	4.5			2703	296	1	1.2	1.5
	220	1.246	44	4.4			2924	256	1	.6	.9
	*221	1.268	39	4.5	40	7	3024	225	1	.8	.9
	*222	1.217	44	4.5	16	16	2872	191	1	.7	1
	223	1.253	39	4.7			2932	221	1	.9	1.1
	*224	1.161	40	4.5	32	34	2914	205	1	1	.8
	*225	1.227	39	4.5	66	18	2929	162	1	1	1.2
	*226	1.206	41	4.5	21	18	2980	227	2	1.2	1.2
	*227	1.16	64	4.5	23	13	3452	191	2	.9	1
	*228	1.179	41	4.5	27	28	3048	191	2	.9	.7
	*229	1.124	38	4.5	25	22	2900	189	2	1.1	.7
	*230	1.165	38	4.6	9	13	2921	188	2	.9	.9
	*231	1.04	40	4.5	17	28	2892	190	2	1	.9
	*232	1.148	48	4.5	20	34	2931	171	1	1	1.1
	*233	1.154	59	4.7	35	53	2894	190	1	1.2	1.2
	234	1.276	51	4.4			3300	167	1	1	.9
1 November 79	*235	1.469	35	4.5	29	24	3612	191	1	1.3	1.6
	*236	2.852	15	4.5	85	47	2532	120	3	1.5	1.6
	*237	1.856	20	4.6	56	40	2671	140	3	1.2	1.1
	238								3		
	*239	1.668	35	4.6	55	43	2729	92	2	.9	.9
	*240	1.615	29	4.5	34	32	2524	123	2	1.2	1.4
	*241	1.46	35	4.5	35	31	2908	137	2	1.1	1
	*242	1.493	38	4.5	29	30	2624	133	2	.9	1.1
	*243	1.151	45	4.6	31	30	2668	134	2	1	1.2
	*244	.784	58	4.5	43	47	2720	147	2	1	1.1
	*245	1.635	27	4.2	32	22	2741	164	2	1.1	.9
	*246	1.392	31	4.6	13	18	2730	119	2	1.5	1.7
	247	1.296	36	4.5	19	22	2871	122	2	1.5	2.6
15 November 79	*248	1.203	36	4.5	23	19	2893	138	1	1.6	1.6
	249	1.144	36	4.5	23	20	2540	133	1	1.2	2.6

DAY	FLOW	UNDER FLOW(%)	MCRT	NTSS	STSS	MLSS	SVI	GATE	N BLANKET	S BLANKET
*250	1.05	53	3.9	16	16	2968	140	1	1.2	1.2
*251	1.031	48	4.5	20	28	2894	199	1	1.1	1.3
*252	.985	61	4.6	15	11	2969	109	1	1.1	1
*253	1.12	38	4.6	7	16	2914	188	2	.9	1
*254	1.063	43	4.4	47	47	1264	119	2	1.9	1.6
*255	1.027	43	4.4	31	20	3236	142	2	1.2	1.3
*256	.919	43	4.5	17	19	3748	119	2	1.2	1.1
*257	.996	41	4.5	45	19	3044	154	2	1.1	.9
*258	.921	69	4.5	23	23	2984	168	2	1.3	1.3
*259	.919	69	4.6	22	15	2999	116	2	1.4	.8
*260	1.018	54	4.6	58	41	2888	147	1	1.1	1
*261	.944	54	4.8	28	55	3392	147	1	1.2	1.2
*262	.99	63	4.5	14	20	3000	151	1	1.1	1.1
*263	1.044	58	4.5	78	24	3032	160	1	.9	1
*264	.985	60	4.5	42	30	3008	112	1	.9	1.2
1 December 79*265	.934	94	4.5	42	50	2894	147	1	1.4	1.2
266	.905	55	4.5			2984	184	1	1.1	1.1
267	1.041	53	4.9	37	40	1496	100	1	2	2.8

APPENDIX C

PLOTS OF OPERATING AND PERFORMANCE DATA FOR THE FOUR AVERAGING PERIODS OF THE 267-DAY STUDY AT HOLLY HILL, FLORIDA

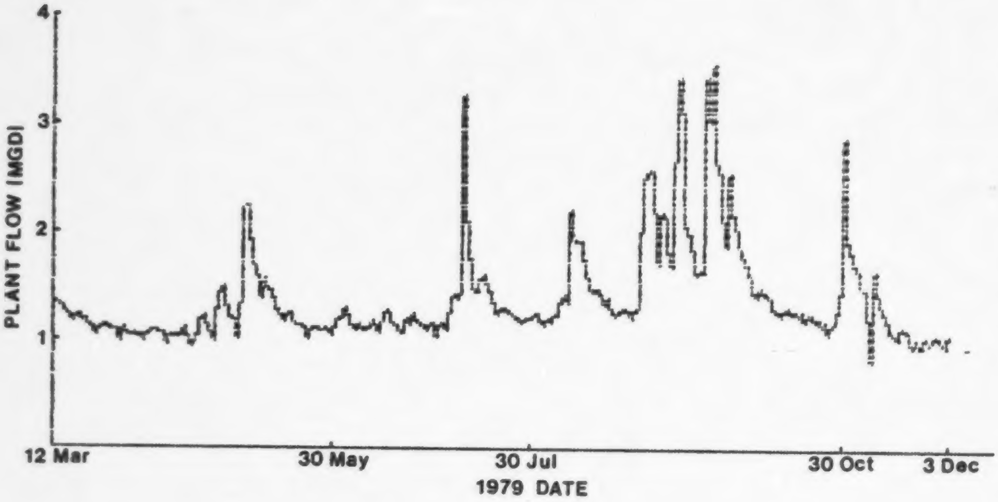

Figure C-1. Total plant effluent rate.

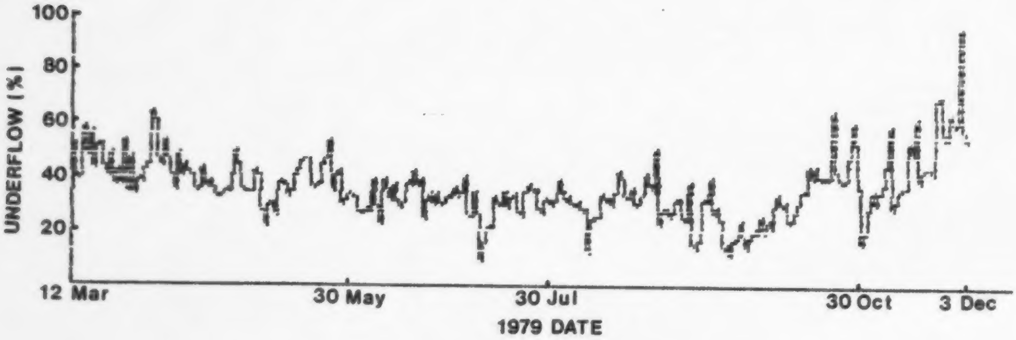

Figure C-2. Percent return sludge rate.

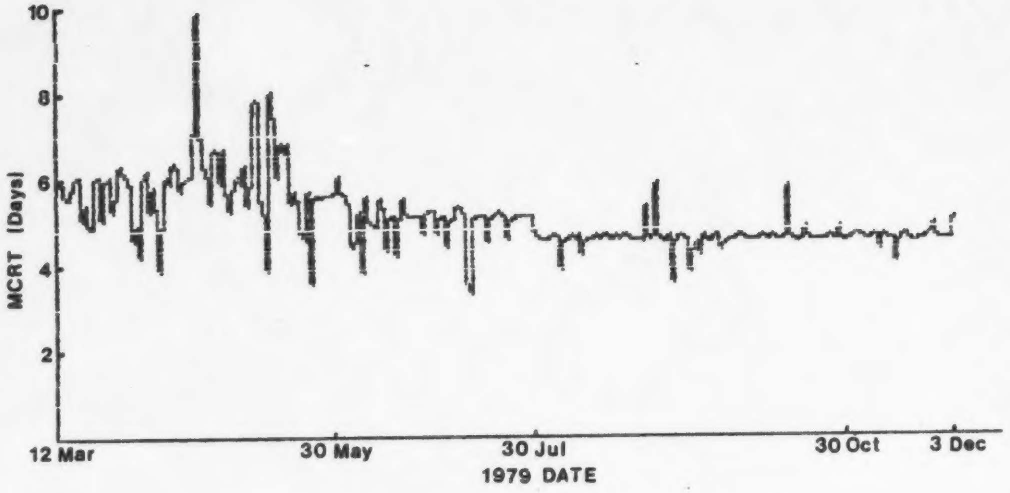

Figure C-3. Mean cell retention time.

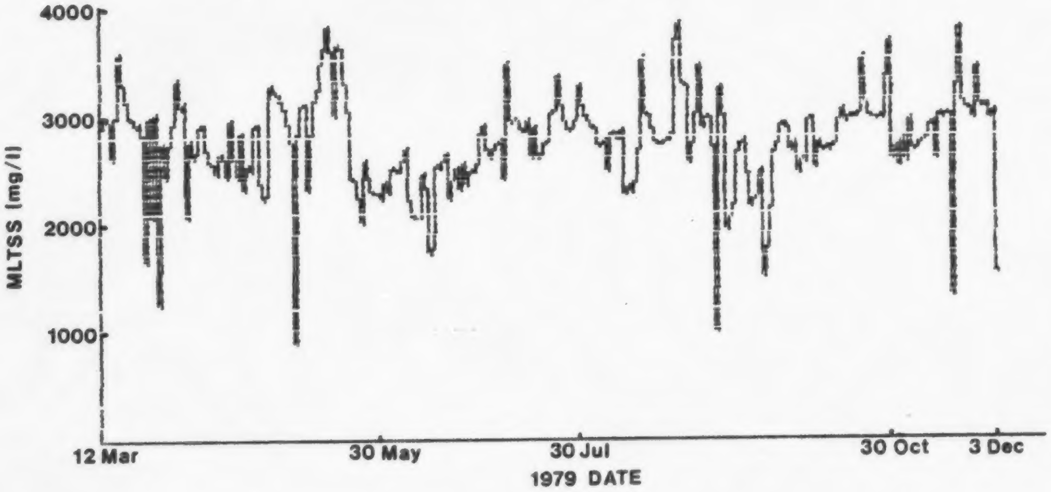

Figure C-4. Mixed liquor total suspended solids.

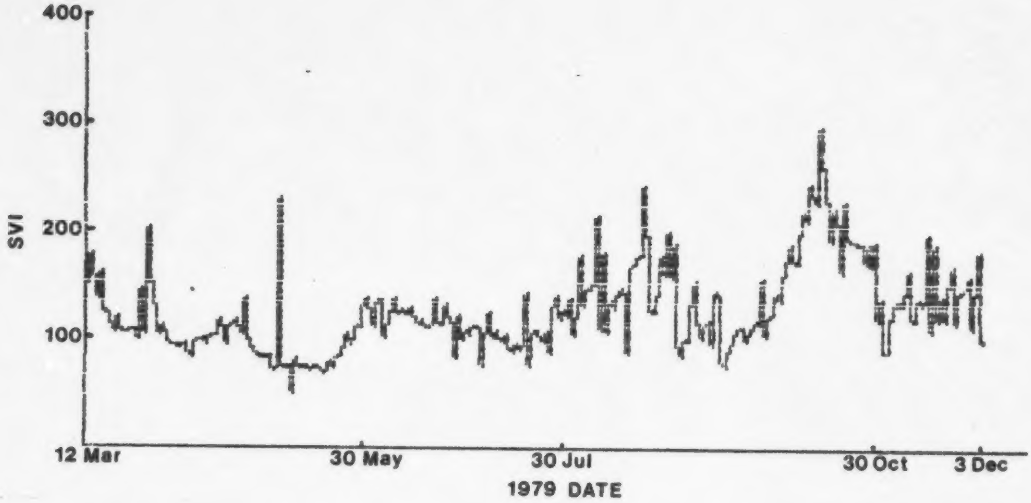

Figure C-5. Sludge volume index.

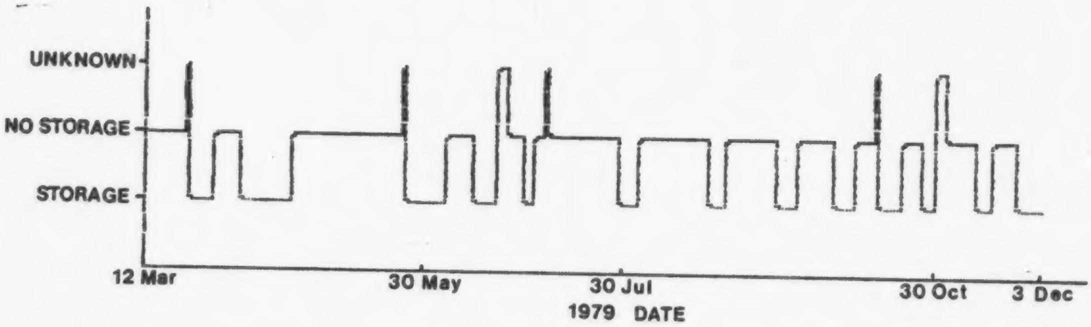

Figure C-6. Status of storage gate.

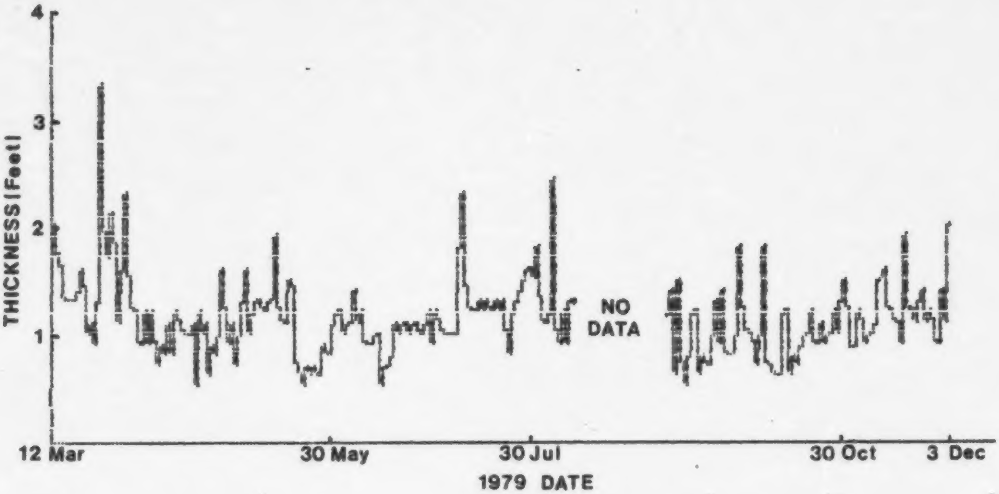

Figure C-7. Blanket thickness in the north clarifier.

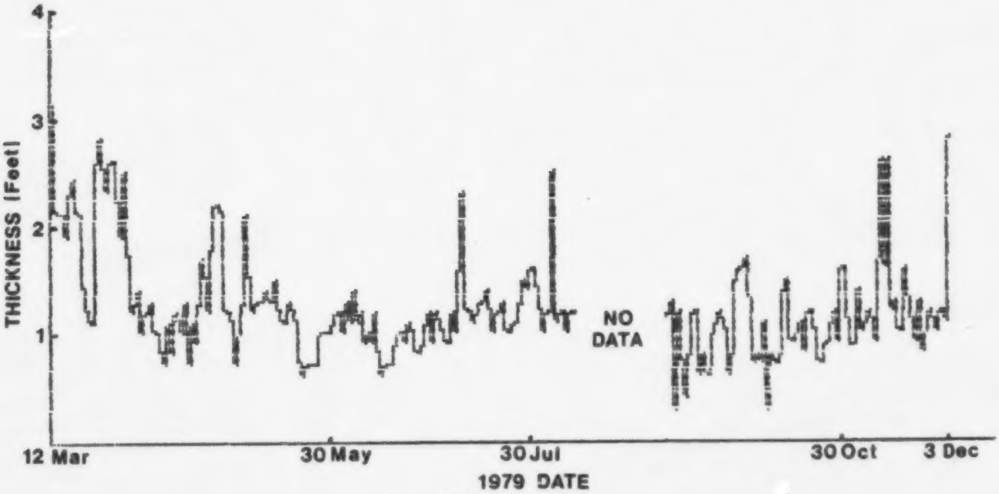

Figure C-8. Blanket thickness in the south clarifier.

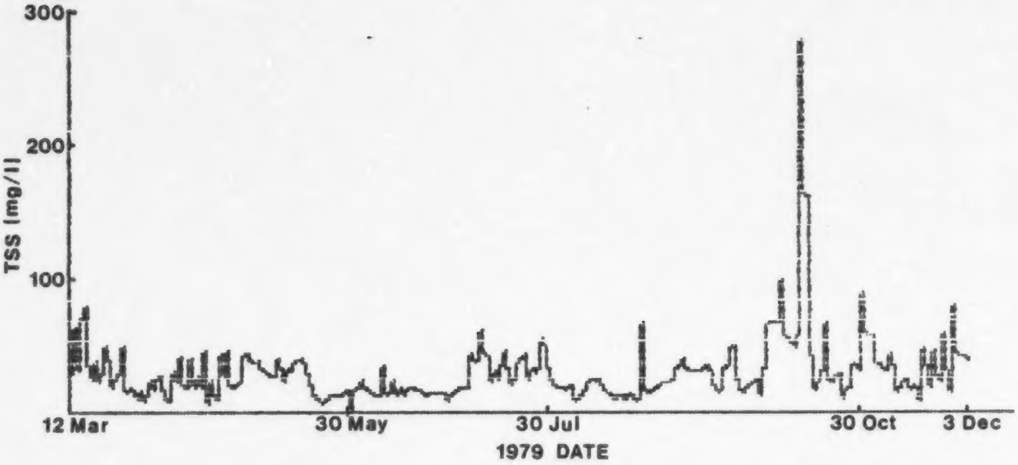

Figure C-9. Effluent total suspended solids, north clarifier. Points plotted for days with missing data were linearly interpolated.

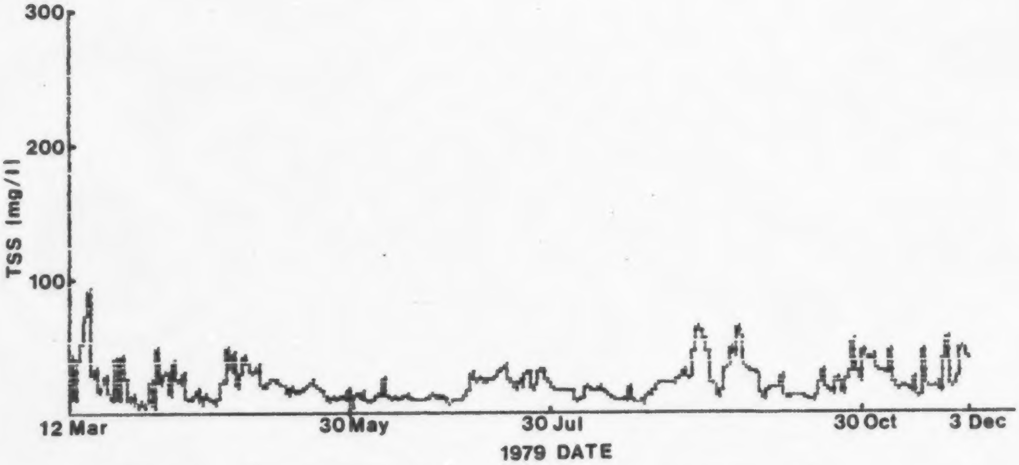

Figure C-10. Effluent total suspended solids, south clarifier. Points plotted for days with missing data were linearly interpolated.

APPENDIX D

MORGANTON, NORTH CAROLINA OPERATING AND PERFORMANCE DATA FOR THE PERIOD 13 SEPTEMBER 1979 TO 12 JANUARY 1980

Sludge Header slowed to 56%.

Units for data are:

Flow, Underflow - mgd
Flow Fraction Test (clarifier) - %
TSS Test (clarifier effluent), TSS CTRL (clarifier effluent), MLTSS, COD Test (clarifier effluent), COD CTRL (clarifier effluent) - mg/l
Blanket Test (clarifier), Blanket Ctrl (clarifier)- thickness, ft

DAY	FLOW	UNDER FLOW	FLOW FRAC. TEST	TSS TEST	TSS CTRL	MLTSS	SVI	BLKT TEST	BLKT CTRL	COD TEST	COD CTRL
1	4.247	2.7	55.1	18	24	7550	38	2	2	178	188
2	4.47	2.7	55.1	11	21	7158	36	1.5	1.7	138	188
3	4.019	2.7	55.1	32	29	6250	48	2.5	2.5	192	192
4	4.232	2.7	55.1	25	30	5600	50	2.2	2.3	212	216
5	4.818	2.7	55.1	28	13	7950	38	2.3	2	190	171
6	4.575	2.7	50.7	13	9	9250	31	2.5	2.5	163	171
7	5.085	2.7	50.7	35	92	8850	33	2.4	2.4	194	266
8	6.994	3.5	50.7	26	66	9750	31	3.6	5.1	64	120
9	3.072	2.7	50.7	34	50	8150	34	1.5	1.6	70	80
10	4.696	2.4	50.7	20	22	6550	38	1.6	2	176	188
11	4.219	2.4	50.7	14	31	8650	29	1.4	2.1	196	236
12	4.328	2.7	50.7	29	33	6050	50	2	2.3	228	243
13	4.756	2.4	48	27	34	7150	45	2.5	2.3	236	247
14	5.093	2.7	48	32	27	7000	41	1.8	2	116	112
15	7.932	2.8	48	42	34	8200	36	3.6	4.6	168	172
16	6.063	2.8	48	44	46	10900	30	2.4	2.9	292	308
17	5.438	2.8	48	25	28	9750	32	2	3	208	196
18	5.857	2.8	52.9	33	28	9000	33	2	2.2	228	232
19	4.89	2.8	52.9	27	26	4250	64	2.9	2.7	172	164
20	3.225	2.8	52.9	26	24	10600	47	3	2.6	96	104
21	3.294	3.4	52.9	22	22	6850	66	2.4	2	96	108
22	3.979	3.4	52.9	34	40	6600	55	2.3	1.9	200	196

DAY	FLOW	UNDER FLOW	FLOW FRAC. TEST	TSS TEST	TSS CTRL	MLTSS	SVI	BLKT TEST	BLKT CTRL	COD TEST	COD CTRL
23	4.037	3.4	52.9	25	24	7550	49	2.1	2.3	198	213
24	4.321	3.4	52.9	24	20	6900	55	2.8	2.5	144	163
25	4.698	3.4	53.1	25	44	7050	58	3.4	3	180	196
26	4.136	3.4	53.1	26	27	8000	56	3	3	192	200
27	3.2	3.4	53.1	18	8	6900	65	1.5	1	103	95
28	3.039	3.4	53.1	11	14	8100	47	2	1.9	65	68
29	4.216	3.4	53.1	25	23	6750	55	2.8	2.5	175	177
30	4.292	3.4	53.1	26	32	9100	43	2.3	2.1	211	212
31	4.257	2.4	53.1	29	24	7100	49	2.3	2.3	196	184
32	3.945	2.4	51.3	11	12	9900	42	2.3	1.7	160	164
33	4.083	2.4	51.3	20	20	8350	44	3	2.8	172	180
34	2.759	2.4	51.3	36	26	9500	48	2.9	2.8	148	144
35	3.86	2.4	51.3	15	31	5850	55	2.5	2.5	180	204
36	3.775	2.4	51.3	27	30	7300	49	1.8	2.2	196	224
37	3.978	2.4	51.3	16	20	8050	45	1.9	1.9	236	236
38	3.376	2.6	48.8	28	24	10000	39	2.2	2.6	211	209
39	3.458	2.6	48.8	15	24	8250	52	1.3	1.1	160	182
40	3.181	2.6	48.8	26	26	8050	47	2.8	2.9	158	190
41	3.403	2.6	48.8	25	24	6900	49	2.8	2.6	0	240
42	3.446	2.8	48.8	10	16	8250	41	2.5	2	228	232
43	3.518	2.8	47.7	17	16	6000	58	2.2	2.2	186	182
44	5.061	3.5	47.7	15	33	7000	60	3.7	4	141	182
45	2.687	2.8	47.7	14	12	9250	43	2.2	2.2	95	95
46	2.325	2.8	47.7	22	22	7500	53	2.5	2.3	95	95
47	3.575	2.8	47.7	17	19	6400	42	1.2	1.3	124	128
48	4.237	2.8	47.7	13	22	6600	48	1.5	1.8	190	208
49	4.6	2.8	47.7	20	29	5900	50	1.5	2	179	182
50	4.271	2.8	49.3	22	18	6050	45	1.8	2.3	217	171
51	4.342	2.8	49.3	30	48	8250	40	1.8	1.8	209	228
52	4.215	2.8	49.3	40	56	6150	49	1.6	1.6	137	152
53	4.333	2.8	49.3	53	36	6550	35	1.6	1.6	268	280
54	4.684	2.8	49.3	35	35	5550	50	2	1.8	200	220
55	5.326	2.8	49.3	42	40	8250	45	2	2.2	212	200
56	4.024	2.8	49.5	42	22	5400	61	1.8	1.6	223	194
57	4.372	2.8	49.5	16	28	5700	65	2.7	2.8	156	216
58	4.362	2.8	49.5	9	9	8800	43	2.8	2.6	120	108
59	2.597	2.8	49.5	15	12	6950	52	2.7	2	92	96
60	3.915	2.8	49.5	30	23	8400	40	2	2.2	205	194
61	4.228	2.8	49.5	31	25	9300	38	2.7	2.5	257	258
62	3.715	2.8	49.5	24	32	8050	43	2.5	2.7	172	176
63	3.499	2.8	51.1	26	22	9600	44	2.8	3	161	211
64	2.822	2.8	51.1	37	29	9300	43	1.9	1.5	163	144
65	4.301	2.8	51.1	38	28	9200	53	5.3	5.3	213	224
66	4.545	2.8	51.1	22	18	6450	65	5	5.4	304	280
67	4.378	2.8	51.1	32	40	7700	61	4.6	4.8	304	296
68	4.104	2.8	40.5	28	36	7600	66	5.2	4.4	280	220
69	4.113	3.4	40.5	30	30	8150	55	5.4	5.4	204	208

DAY	FLOW	UNDER FLOW	FLOW FRAC. TEST	TSS TEST	TSS CTRL	MLTSS	SVI	BLKT TEST	BLKT CTRL	COD TEST	COD CTRL
70	2.722	3.4	40.5	16	24	11550	65	4.8	4.5	141	163
71	2.346	2.8	40.5	18	30	8400	81	5	4	118	137
72	3.883	2.8	40.5	24	30	6350	79	5.9	5.3	148	184
73	4.275	3.4	40.5	28	38	7900	59	7.4	6.7	190	167
74	4.021	3.5	40.5	21	20	6500	63	7	6.2	205	205
75	3.914	3.5	50.4	27	30	8800	58	5.5	6.1	201	243
76	2.695	3.5	50.4	34	46	8100	65	4.7	4	182	194
77	3.502	3.8	50.4	90	104	7400	50	4.9	5.5	283	258
78	4.044	3.6	50.4	54	62	7550	64	4.8	5.1	228	209
79	3.855	3.5	50.4	33	39	9000	54	5.6	6.6	260	256
80	3.922	3.3	50.3	19	32	9800	47	5.1	4.6	216	216
81	3.789	3.1	50.3	32	54	8350	61	5.1	5	252	256
82	2.731	3.1	50.3	30	34	11280	55	4.4	3.8	160	163
83	2.25	3	50.3	52	86	0	33	3.2	2.7	190	213
84	3.536	4	50.3	44	60	8250	51	4.4	3.9	220	236
85	3.772	4	50.3	54	48	9900	56	4.7	4.8	281	281
86	4.012	4	50.3	48	30	7750	61	4.4	4.9	276	268
87	4	4	52.3	64	52	7350	65	5.4	5.9	270	266
88	3.804	4	52.3	36	46	9800	51	4.8	5.3	243	258
89	3.035	2	52.3	84	120	9350	55	4.2	3.2	232	257
90	3.668	2	50.6	36	62	6800	68	3.1	3.3	302	319
91	3.602	2	50.6	48	28	7450	63	2.9	2.9	352	344
92	2.584	2	50.6	24	18	8500	60	3	3.1	175	167
93	2.444	2	50.6	18	30	4650	73	2.8	2.2	148	156
94	3.416	2	50.6	32	44	4800	68	3	2.6	239	247
95	2.893	2	50.6	20	28	6250	62	3	2.7	236	247
96	3.71	2	50.6	22	26	3725	87	3.1	2.3	324	316
97	3.797	2	53.8	26	28	7250	58	3.2	3	288	268
98	4.522	2.2	53.8	16	16	5700	65	3.3	2.3	304	300
99	2.5	2.4	53.8	18	6	8050	56	3.3	2.6	171	163
100	2.166	2.4	53.8	20	44	7500	55	2.8	2.9	148	152
101	3.666	2.4	53.8	38	42	6500	49	2.8	2.7	209	220
102	3.74	2.4	53.8	8	26	7650	44	2	1.9	209	211
103	3.607	2.4	53.8	34	30	7550	40	2.6	2	182	163
104	3.814	2.4	50.8	30	44	7700	43	2.7	2.6	228	289
105	4.012	2.4	50.8	38	36	6900	54	2.6	2.3	236	228
106	4.528	2.4	50.8	26	42	9050	39	2.6	2.6	205	194

APPENDIX E

MORGANTON, NORTH CAROLINA OPERATING AND PERFORMANCE DATA FOR THE PERIOD 15 MAY TO 4 SEPTEMBER 1980

Slowed sludge header and ring baffle/flocculation chamber in place.

Units of the columns are:

Flow (Clarifier) No. 1, (Clarifier) No. 2 - m^3/d
(Effluent) TSS (Clarifier) No. 1, No. 2, MLTSS - mg/l
Blanket No. 1 (In) side Ring - ft (thickness)
Blanket No. 1 (Out) side Ring - ft (thickness)
Blanket No. 2, mid radius - ft (thickness)

REC	FLOW NO.1	FLOW NO.2	TSS NO.1	TSS NO.2	MLTSS	SVI	BLANKET NO.1(IN)	BLANKET NO.1(OUT)	BLANKET NO.2
1	6121	6656	12	22	8500	39	4.8	2.7	4
2	3953	4378	12	18	9050	36	3.2	2.2	3.3
3	4120	4340	4	18	6400	52	4.7	2.5	3.4
4	2478	2798	24	34	6950	53	3.9	1.6	1.7
5	4018	4249	28	30	5850	51	4.4	1.6	2.2
6	3864	4365	18	26	5850	55	4.7	2.9	3.1
7	3851	4535	20	36	6600	58	4.6	2.8	3.3
8	3979	4626	16	18	6100	61	4.7	2.5	4.6
9	4120	4044	20	40	6500	62	5.9	3.3	3.8
10	4018	3967	6	4	4750	72	4.5	2.6	2.4
11	3992	4018	12	22	5200	60	5.1	2.3	2.5
12	4018	3966	8	8	5450	57	4.3	2.2	2.8
13	4056	3979	16	30	6250	51	4.4	1.5	1.8
14	4121	3927	34	54	4400	62	4.6	2.5	2.3
15	4145	4160	42	44	4500	58	4.7	1.8	1.9
16	4120	4327	38	24	4300	65	4.3	2.1	1.8
17	4107	4327	32	42	6400	47	4.5	2.8	2.1
18	4326	4511	40	44	4700	55	4.2	1.9	1.8
19	3623	4535	4	26	3500	51	4.3	1.7	1.4
20	3623	4535	18	50	3850	47	4.3	1.5	2.2
21	4030	4172	8	20	2950	58	4	1.2	1.8
22	4300	4731	16	20	4550	53	4.5	2	2.4
23	9264	9520	84	28	5350	49	7.2	4	3.9
24	4069	3966	16	14	5450	48	4.9	2.7	3.1
25	4120	3864	22	34	8000	39	5.4	2.8	2.8
26	4352	4378	16	30	3900	59	4	1.8	1.8

REC	FLOW NO.1	FLOW NO.2	TSS NO.1	TSS NO.2	MLTSS	SVI	BLANKET NO.1(IN)	BLANKET NO.1(OUT)	BLANKET NO.2
27	4031	4940	6	20	3150	48	3.5	1.2	1.5
28	2326	2752	4	4	3250	49	2.4	1.4	1.6
29	4378	3548	26	4	3500	43	2.5	1.3	1.1
30	4248	4185	38	36	3950	43	2.8	1	1.3
31	3915	4353	16	18	5250	46	3.8	1.6	1.5
32	3335	3992	12	18	4100	46	3.3	1.1	1.2
33	3699	3966	12	28	4700	45	2.8	1.5	1.8
34	3762	3915	8	12	3250	49	2.8	1.4	1.2
35	7110	7190	8	8	5750	35	4.2	1.3	1.5
36	4171	4365	12	20	3900	49	4	1.8	1.8
37	3813	4223	4	12	4750	51	2.7	1	1.1
38	3736	4378	6	14	4800	50	3.4	1.4	1.5
39	3762	4326	24	46	5050	50	3.4	1.4	1.3
40	4172	4223	16	38	3200	53	3.6	1.4	1.8
41	3787	4171	16	18	5150	49	3.3	1.1	1.2
42	3826	3993	12	32	5650	32	4.1	1.2	1.7
43	3979	4070	20	32	3550	42	4	1.3	1.2
44	4017	4430	12	16	4300	51	3.4	1.7	1.6
45	3635	4301	10	20	3750	59	3.8	.7	1.1
46	3762	3940	10	40	4200	48	3.2	1.3	1.4
47	3953	4404	50	128	2800	54	2.8	1	1
48	3787	3966	18	58	2700	41	3	.8	1
49	3813	4068	12	38	3150	54	2.9	.9	.9
50	3736	4223	20	38	3450	52	2.6	1.5	1.3
51	3623	4017	4	16	4100	54	3.5	1.4	1.8
52	4339	4301	10	26	4500	49	3.5	1.3	1.5
53	4096	4352	4	20	6300	54	3.3	1.8	1.9
54	3790	4171	22	26	3300	55	3.6	.7	.8
55	4068	4301	6	26	3700	59	2.9	1.9	1.6
56	4068	4172	12	18	3350	54	3.8	1.5	1.6
57	3914	4457	14	40	3650	52	3.3	.6	1.2
58	2990	4301	6	22	6400	27	3.3	.6	1
59	4171	4612	12	22	3000	50	3.8	.8	.8
60	4562	3889	28	40	3450	52	4.8	1.4	1.3
61	3585	3698	52	80	8150	49	6.3	5.9	5
62	3979	4275	62	34	10150	52	5.9	6.9	7.8
63	4145	4018	28	28	7650	61	6.8	6.6	8.1
64	3953	3877	14	20	8150	47	7.8	8	8.5
65	4057	3992	6	6	5850	59	6.9	5.4	5.7
66	3992	3954	10	8	6400	59	6.3	5.9	6.4
67	3992	3967	10	14	6100	75	6.9	6.4	7.2
68	4081	4018	12	8	6700	67	7.4	6.8	6.9
69	4017	3813	12	14	5750	66	6.3	5.8	5.8
70	3940	3915	18	20	8100	62	6.8	6.4	6.1
71	4171	4198	44	42	7250	65	7.8	7.3	7.1
72	4223	4275	22	26	5400	85	8.1	7.7	7.5
73	4482	4198	108	26	7000	67	7.8	7.1	7
74	4145	4108	52	188	5200	85	8.1	7.5	7.7

REC	FLOW NO.1	FLOW NO.2	TSS NO.1	TSS NO.2	MLTSS	SVI	BLANKET NO.1(IN)	BLANKET NO.1(OUT)	BLANKET NO.2
75	3953	4147	420	840	7100	59	8.8	8.4	8.9
76	3903	4198	8	6	6900	77	7	6.9	7.5
77	4043	4211	124	380	6500	57	7.3	6.9	7.5
78	4069	4366	22	20	0	0	4.4	3.8	3.3
79	3788	4223	18	16	0	0	5.8	4.6	3.7
80	3839	4249	4	6	0	0	5.8	4.6	3.8

APPENDIX F

STAMFORD, CONNECTICUT OPERATING AND PERFORMANCE DATA FOR THE PERIOD 7 JANUARY 1980 TO 7 OCTOBER 1980, WITH THE PERIPHERAL BAFFLE IN PLACE

Only the first 52 data sets were considered valid. The remaining data were not analyzed as explained in the text.

Units for the columns are:

Flow - mgd
MLTSS, (Effluent) TSS No. 1 and TSS No. 2 - mg/l
Blanket No. 1 and No. 2 - ft - (depth from surface to blanket)

REC	FLOW	MLTSS	SVI	BLKT #1	BLKT #2	TSS #1	TSS #2
1	23.328	2060	126	13.5	13	11	17
2	20.656	1960	133	14	14	8.5	10
3	18.842	2060	134	14.5	13.5	8	9
4	18.896	2000	135	13.5	13.5	7	8
5	19.556	2040	136	13.5	14	5	15
6	20.332	1860	136	14	12	6	15
7	19.444	2460	145	14.5	13	5	7.5
8	20.304	2500	135	14	12	7	15
9	20.172	1580	133	13.5	11	40	8
10	20.504	2080	140	14	12.5	11	14
11	20.608	2180	138	14.5	12.5	9	17
12	20.04	1960	143	14	13	7	9
13	21.14	2040	150	14	12	9.5	11
14	20.36	2040	143	14.5	14	10	12
15	23.773	2260	158	14	12	7	7
16	23.716	2150	140	14.5	13	8.5	11
17	23.932	2325	142	14.5	13.5	11.5	9
18	23.124	2400	144	14	14	12	11
19	25.14	2500	139	13.5	13.5	14	18
20	28.628	2750	137	14	14	18	22
21	25.292	2250	135	12.5	11.5	13	19.5
22	25.344	2450	130	12.5	10	11	26
23	24.988	2000	133	13.5	12	8	22
24	25.208	2200	120	13	11	9	16
25	24.919	2250	124	12.5	11.5	9	15
26	25.012	2225	126	12.5	12	9	14

REC	FLOW	MLTSS	SVI	BLKT #1	BLKT #2	TSS #1	TSS #2
27	24.732	2175	124	13	12	7	8.5
28	20.548	2100	124	12.5	10.5	9	12
29	19.716	2050	138	12	10.5	19	22
30	19.632	2075	123	12.5	11.5	18	18
31	20.804	2250	123	12.5	12	14	13
32	19.796	2125	115	12.5	12	9	10
33	24.245	1260	125	13.5	12.5	10	10
34	24.788	2925	137	12	10	9	11.5
35	21.278	2725	130	13.5	12.5	10	11
36	21.878	2225	135	13.5	12.5	8	11
37	21.678	1925	132	13.5	12.5	12	12
38	20.456	2825	152	12.5	12	14	16
39	21.852	2525	161	12	11.5	10.5	16
40	20.096	2675	155	13	10.5	14	22
41	22.982	3475	175	13.5	9.5	11	13
42	25.188	3175	186	12	10	9	14
43	24.931	2000	137	13.5	10	12	29
44	24.04	2975	153	13.5	11	13	16.5
45	27.072	2800	187	13.5	13.5	10	12.5
46	31.98	1400	110	11.5	9	13	26
47	31.576	1325	113	10.5	8.5	17.5	43.5
48	29.556	2425	123	9	8	17	21
49	28.224	1250	109	10.5	8	15	39
50	27.732	2300	87	10.5	5	12	99
51	31.665	1240	105	14	12.5	28	84
52	29.36	1920	104	14	12.5	11	34
53	28.524	1600	118	14	11	10	30
54	28.688	1540	104	14	11.5	10	22
55	26.088	1700	106	14	11.5	10	22.5
56	26.336	1840	115	14	12.5	12	33
57	32.996	1920	86	14	13	22	17
58	31.46	1580	91	13.5	12.5	15	14
59	30.98	1780	95	13.5	12.5	15	16
60	28.029	1680	104	14	13	7.5	7
61	27.816	2400	111	14.5	14.5	11	9
62	26.852	1880	106	14.5	14.5	10	11
63	27.572	2200	117	14.5	14.5	10	11
64	27.656	2360	154	14	14	12	10.5
65	27.332	2060	131	14	14	11	12
66	26.072	2180	146	15	15	15	9.5
67	26.052	2000	139	15.5	15.5	10	9
68	26.18	1600	120	14	13.5	10	12
69	26.276	2160	159	13.5	13.5	13.5	12
70	25.896	2220	160	14	14	14.5	12
71	27.056	2520	166	14	13.5	11.5	12
72	29.173	2020	144	14.5	14.5	15	14
73	23.852	2280	147	13.5	13.5	10	13
74	22.892	2120	151	13	13.5	11	10
75	23.66	2580	166	13	13.5	9	10.5

REC	FLOW	MLTSS	SVI	BLKT #1	BLKT #2	TSS #1	TSS #2
76	23.54	2360	161	13.5	13.5	9	14
77	26.28	2140	140	14	13.5	10	10
78	25.024	2180	124	14	13	14	14
79	24.98	3825	141	14	13	12	13
80	26.765	2650	127	14	13	17	18
81	26.285	2160	119	14	13.5	12.5	15
82	27.808	2100	115	14	13.5	10	12
83	23.516	1940	124	14	13	11	8
84	25.788	1680	158	14	13	10	13
85	24.936	1520	118	14.5	14	9	17
86	24.428	2300	109	13.5	14	8	11
87	24.318	1650	121	13.5	12	8	10
88	22.216	1700	124	14	11	8	11
89	22.528	1800	122	13.5	11	9	13
90	21.664	1050	133	14.5	14.5	16	16
91	21.884	1580	114	14	14.5	8	8
92	22.699	940	118	14	14.5	10	11
93	24.136	1220	107	14	14	18	19
94	24.59	1375	98	14	14	19	20
95	23.796	1920	98	14	14	27	27
96	20.408	1425	75	14	14	31	32
97	22.368	2175	67	14.5	14.5	20	22
98	20.809	2350	77	14.5	14.5	17	17
99	21.116	1400	73	14.5	14	25	26
100	20.144	1675	66	14.5	14.5	20	19
101	21.184	1225	74	14.5	14.5	18	19
102	22.651	1100	69	14.5	14.5	17	18
103	19.896	1275	68	14.5	14.5	31	29
104	19.936	1150	74	14.5	14.5	25	28
105	19.669	1700	67	14	14	16	14
106	18.892	1750	83	14.5	14.5	15	25
107	20.087	1525	81	14.5	14.5	13	12
108	20.436	1080	93	14.5	14.5	10	9
109	21.352	1350	97	14.5	14.5	9	11
110	20.846	1375	93	14.5	14.5	8.5	10
111	21.404	1275	87	14.5	14.5	8	9
112	20.868	1375	81	14.5	14.5	11	10
113	21.119	1525	64	14.5	14.5	14	11
114	21.22	1300	66	14.5	14.5	19	18
115	30.492	1400	72	14.5	14.5	27	41
116	22.292	2100	72	14.5	14.5	14.5	15
117	21.6	1275	79	14.5	14.5	10	12
118	26.812	1340	98	14.5	14.5	7	6
119	19.576	1480	92	14.5	14.5	5.5	5
120	18.22	1540	72	14.5	14.5	10	10
121	19.28	1580	98	14	14	8	10
122	22.248	1520	67	14.5	14	5	5
123	19.18	1520	56	14.5	13.5	3	5
124	19.588	2060	60	14.5	14.5	6	9

REC	FLOW	MLTSS	SVI	BLKT #1	BLKT #2	TSS #1	TSS #2
125	18.808	1760	61	14.5	14.5	7	9
126	18.748	2760	74	14.5	14	7	7.5
127	18.64	1720	63	14.5	14	6	8
128	20.26	1880	56	14.5	14	10	11
129	18.508	1880	56	14	14.5	5	6
130	17.984	1580	65	14.5	14	5	6
131	18.348	1360	66	14.5	14	6	7
132	17.864	1600	56	14.5	14	6	11
133	18.475	1320	68	14.5	14	8	9
134	18.788	2720	62	14	14	13.5	21
135	21.464	2920	72	14	13.5	8	15
136	18.64	2240	62	14.5	93.5	11	26
137	17.848	3680	65	14.5	14	14	32
138	18.564	2840	84	14.5	14	9	10.5
139	17.4	2280	88	14	14	16	39
140	18.524	3080	88	14	14	16.5	28
141	17.3	2320	73	14.5	14	16.5	24
142	17.688	3160	92	14.5	14.5	19	18
143	17.7	2280	105	14	14.5	12	17
144	18.212	1920	125	14.5	14.5	13	17